GEOGRAPHICAL BULLETIN

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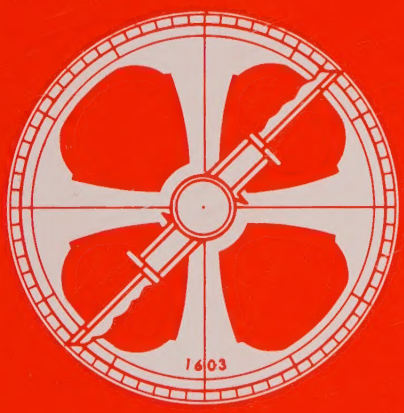

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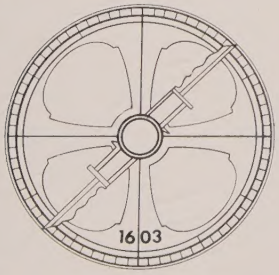
GEOGRAPHICAL BULLETIN

Champlain's astrolabe, lost near the Ottawa River in 1613 and found in August 1867, has been adopted as the symbol of the Geographical Branch. Appointed Geographer to the King of France in 1603, Samuel de Champlain is thus recognized as the forefather of Canadian geography.

The statue of Champlain stands on Nepean Point, Ottawa. The sculptor has used a degree of artistic license in that the astrolabe is held upside down.



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GEOGRAPHICAL BULLETIN, VOL. 7, NO. 2, PP. 73-78, 1965

THE LAND-USE SECTOR OF THE CANADA LAND INVENTORY

J. B. McClellan

ABSTRACT

The Geographical Branch is responsible for the land-use sector of the Canada Land Inventory, a national land-resource inventory sponsored by the Agricultural Rehabilitation and Development Act (ARDA). This paper describes the Canada Land Inventory, the place of land-use mapping in the inventory, the development of a national land-use classification, and its limitations.

RÉSUMÉ

En matière de l'inventaire des terres du Canada, la Direction de la géographie est chargée de la section relative à leur utilisation. Cet inventaire national des richesses en terres agricoles a été parrainé par l'application de la Loi sur la remise en valeur et l'aménagement des terres agricoles (ARDA). Dans cette étude, l'auteur décrit l'inventaire, la place qui est donnée à la cartographie relative à l'utilisation des terres, l'établissement d'un classement national sur cette utilisation et ses limitations.

CANADA LAND INVENTORY

In Canada, in recent years, programs of comprehensive resource management and social planning in rural areas have begun to take shape at the federal level of government under the Agricultural Rehabilitation and Development Act (ARDA) of June, 1961. At the same time provincial governments have been venturing further into the sphere of regional development planning. In order to avoid costly mistakes in the development and implementation of these programs it is apparent that they must be solidly based on an adequate knowledge of the capability and present use of Canadian land resources. For several years many individuals and groups have been calling for a nation-wide land-resource inventory to fill this basic need; the setting up of such an inventory was one of the major recommendations brought forward by both the Resources for Tomorrow Conference, held at Montreal in 1961, and the Senate of Canada Special Committee on Land Use.

On October 3, 1963, a full-scale appraisal of Canada's land resources was officially launched, when the Government of Canada approved the establishment of the Canada Land Inventory as a research project under the ARDA program (ARDA, 1964). The purpose of the inventory is to bring together all relevant data on the capabilities and uses of land in the settled parts of Canada, to fill the substantial gaps in the data, and to present the findings in classification schemes suitable for a wide variety of uses. As now constituted, the inventory includes the following sectors:

(a) Soil capability for agriculture,
(b) Soil capability for forestry,
(c) Land suitability for recreation,
(d) Land suitability for wildlife,
(e) Present land use,
(f) Socio-economic land classifications,
(g) Agro-climatology classification.

The inventory is being planned and developed cooperatively by the federal and provincial governments. Approximately one hundred government agencies, as well as numerous universities, private companies and non-governmental organizations, will be involved in the project before it is completed. To handle the large volume of data that will be collected a system of computer mapping is being developed that will permit the storage and analysis of data derived both from maps and from statistical tables (Tomlinson, 1964).

The inventory is of a reconnaissance type; within each sector the emphasis has been placed upon

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rapid coverage of large areas, using a limited number of broad categories. It is designed to provide information needed for resource development *planning* at the municipal, provincial, and federal levels of government. It will not provide the detailed information needed for the *management* of small parcels of land.

THE PLACE OF LAND-USE MAPPING IN THE INVENTORY

Unless a land-use mapping system is designed to supply specific answers to specific questions, its value in land-use planning will be very limited. As Ullman (1953) has stressed, it should be geared to concepts; otherwise the mapping tends to become a mechanical operation geared only to fill in the empty spaces on the map.

For the purposes of the Canada Land Inventory a relatively simple present land-use classification was needed that would assist in estimating the location and extent of areas where changes in the land-use pattern are desirable. It would supply planners at the provincial and federal levels of government with a better framework in which to make their decisions. Specifically, the classification was designed to provide two types of information.

Firstly, it is an estimate of the location and extent of major land uses. Measurement on the land-use maps will provide quantitative estimates of the amount of land now occupied by built-up urban areas, devoted to outdoor recreation, used for various types of farming, and for the non-agricultural sectors the area of the various cover types. Most of these will be estimates available from no other sources, or if available, scattered throughout a wide variety of sources. To cite only one example, a recent Geographical Branch land-use survey in Prince Edward Island revealed that the actual woodland acreage was almost double most previously accepted estimates (Raymond, et al., 1963). In the absence of a forest inventory, a census estimate of 330,000 acres was generally quoted, based on the acreage of woodlots on occupied farms. Measurement of the land-use maps, which included the land not in farms, showed the actual area of woodland to be 600,000 acres.

Secondly, and of more importance, is the comparison between present use and assessed capability of land; this can be derived by matching the land-use maps against the capability maps produced in other sectors of the inventory, through the medium of the computer. The following examples suggest the type of information that can be obtained through a process of computer cross-classification:

—location and extent of land now under cultivated crops but with soils that are unfavourable to the production of these crops.

—location and extent of land now abandoned, idle or extensively used that is capable of producing cultivated crops or perennial forage crops.

—nature of the present cover on land suitable for reforestation.

—nature of the present cover on land rated highly for recreational purposes.

To those engaged in long-range resource planning the benefits to be derived from information of this type will be considerable. The examples cited also illustrate the greater utility of present land-use mapping for planning purposes when it is coordinated with surveys done by other disciplines within the framework of an integrated program of resource study.

At various times it has been suggested that, at the reconnaissance level of survey necessary for the purposes of the Canada Land Inventory, an adequate method of portraying present land use would be to use statistics from the 1961 Census of Agriculture. In fact, data derived from land-use maps complement the census statistics, rather than duplicate them. By blending the results derived from both techniques of data gathering, a clearer picture of present land use would emerge for an area than if either technique were used alone.

The Census of Agriculture presents data for farmland only, yet even in the long-settled parts of Canada the difference between total land area and total area of occupied farmland is considerable. For example, in Prince Edward Island, the province with the largest proportion of its surface devoted to agriculture, only 69 per cent of the total area was classified as occupied farmland in the 1961 census. Urban areas, summer cottage colonies, bogs, beaches, abandoned farms and large tracts of woodland are not included within the scope of the census. In many marginal areas where an alternate use of land is being considered, census figures are not complete enough to show a picture of existing land use.

A further difficulty in the use of census data arises at the township or census subdivision level, where distortions occur in the reported farmland acreages because of the census practice of tabulating for the township the total acreage owned or rented by the farmers whose headquarters are in that township. In areas where farmers in one

municipality own or rent large amounts of land in a neighbouring municipality the distortion is often considerable. MacDougall (1962) has cited the case of a township in Victoria County, Ontario, where the census figure for improved land in 1956 was less than half the figure for developed agricultural land, as measured from forest inventory maps in 1957. Presumably, much of the improved land in the township was owned or rented by farmers residing in other townships.

Even more significant from the standpoint of the inventory, however, is the fact that maps prepared from census data do not reveal the precise location and pattern of the various uses of land. These details of location are vital for the comparison of land-use maps with capability maps from other segments of the inventory. In Renfrew County, Ontario, for instance, the clay plains are intensively farmed while much land abandonment has occurred on the rock-knob uplands and sand plains. The relationship between present use and soil capability is clearly revealed when the land-use map is superimposed on the capability map, either visually or by means of the computer; the relationship would not be as readily apparent if the present land-use map was constructed from census data on a township basis, especially where townships include sections of both upland and lowland. Use of census land-use data, generalized on a sub-division basis, would detract from the ability of the computer mapping system to cross-classify information on a natural boundary basis.

On the other hand the census can provide types of data relevant to present land use that would be extremely difficult to provide through reconnaissance land-use mapping. Information on size of farm, land tenure, density of livestock populations and acreages of individual crops is important in presenting a complete description of present use in an area. Census data, already available on computer tape at the Dominion Bureau of Statistics, will be used as a source for socio-economic land classifications, which are a separate segment of the inventory.

THE ROLE OF THE GEOGRAPHICAL BRANCH

As the federal agency most closely associated with the development of land-use mapping in Canada, the Geographical Branch was asked to develop a national system of classification for present land use for the inventory. In addition, the Branch is producing all of the maps of eastern Canada necessary for the project. For the four western provinces, the mapping is being done by other agencies, and the Branch is providing co-ordination in the application of the classification.

THE DEVELOPMENT OF THE CLASSIFICATION

Work on the development of a classification to meet inventory needs began in the late spring of 1963. In constructing the classification a wide variety of factors was taken into consideration; of these the most important were the following:

Area to be Covered and Time Involved

The Canada Land Inventory covers the agriculturally settled portion of Canada and adjoining areas which affect the income and employment opportunities of rural residents, a total area of approximately 1,100,000 square miles. To cover this area at a scale of 1:50,000, which is the working scale for the inventory, more than 3,000 National Topographic System half-sheets, each covering 225 square miles, are required. It was hoped that the work would be completed within four years from the beginning of the project.

The Geographical Branch has been engaged in a program of land-use studies since 1950 (Nicholson, Cornwall and Raymond, 1961). Most of the mapping has been done using a field-by-field survey technique, with individual crops or groups of crops as the basis of the classification. To map a 1:50,000 half-sheet required the services of one geographer working for three weeks in the field. However, it would be impossible to complete the Canada Land Inventory in the allotted time by continuing this detailed type of field mapping, unless the size of the staff at the Branch were to be greatly expanded. Air photograph interpretation, supplemented by limited field checking, was clearly indicated as the only available means for the rapid coverage of large areas.

Over most of southern Canada the scale of available air photographs ranges between 1:10,000 and 1:30,000, and the season in which they were taken varies from early spring to late autumn. The wide range of available coverage precludes the possibility of individual crop interpretation. To avoid unnecessary expense it was decided to keep to a minimum the amount of new photographic coverage flown specifically for the project, and to rely mainly on existing coverage. In establishing the classification, then, the various categories had to be capable of identification on existing air photographs.

Use of Existing Information

A large amount of work has been done on present land use in recent years. Within the past five years the Geographical Branch has published, or now has in manuscript form land-use maps covering all of Prince Edward Island and Nova Scotia, most of New Brunswick, and small parts of Alberta, British Columbia, Newfoundland, Ontario and Saskatchewan. In addition, a considerable amount of mapping has been done by university students and staff, and various provincial and municipal agencies. In order to avoid duplication of this work, the classification was designed so that most existing land-use maps could be used with a minimum of re-interpretation.

By July, 1963, a preliminary classification had been drawn up and was ready for testing. Mapping was done in two ARDA Rural Research Regions, the eleven eastern counties of Ontario and the Gaspé region in Quebec. The work revealed several flaws in the classification and during the winter of 1963-64, a revised classification was prepared. In the spring of 1964 the revised classification was submitted for criticism to the chairmen of all university geography departments in Canada and to government officials concerned with land-use problems. By December, 1964, a final version of the classification had been drawn up, incorporating suggestions made by the critics, and a detailed manual describing the application of the classification had been prepared. The classification that follows is the recommended classification for use across Canada at the Federal level.

PRESENT LAND-USE CLASSIFICATION FOR CANADA LAND INVENTORY

Urban

Land used for urban and associated non-agricultural purposes.

(a) *Built-up area*
Land occupied by the built-up portions of cities, towns, and villages, as well as isolated units away from settlements such as manufacturing plants, rail yards, and military camps.

(b) *Mines, quarries, sand and gravel pits*
Land used now, or in the past, for the extraction of earth materials.

(c) *Outdoor recreation*
Land used for private or public outdoor recreational purposes. The sub-category includes the land occupied by summer cottages and associated beach areas, parks, golf courses.

Horticulture

Land used for the intensive production of vegetables and small fruits. Market gardens, nurseries, flower-growing areas and sod farms are included in this category. Farm holdings are usually small and intensively cultivated.

Orchards and vineyards

Land used for the production of tree fruits and grapes.

Cropland

Land used primarily for cash crops, usually in rotation. Cash grains, oilseeds, sugar beets, potatoes, field beans and peas, and any associated fallow land are included in this category. Feed grains grown for use on the farm are also included in this category.

Improved Pasture and Forage Crops

Land used primarily for the production of improved pasture and hay.

Unimproved Pasture and Range Land

Grasslands such as natural range, rough pasture and scrub grassland.

Woodland

Land covered with tree or scrub growth.

(a) *Productive woodland*
Land bearing forest of a commercial character. Artificially restocked areas, or plantations, are included in this sub-category, regardless of age.

(b) *Non-productive woodland*
Land covered with scrub growth. The sub-category includes recently cut-over and burnt-over areas.

Swamp, marsh or bog

Open wetlands of all types.

Unproductive Land

Land that is biologically unproductive in its present state.

(a) *Sand flats, dunes and beaches*
Land on which an exposed sand surface predominates.

(b) *Rock and other unvegetated surfaces*
Rock barrens, badlands, eroded river banks, etc.

The greatest difficulty in applying the classification lies in the interpretation of Categories 4 (Cropland) and 5 (Improved Pasture and Forage Crops). Grain crops can be consistently distinguished from hay and pasture on air photographs only when the photographs have been taken during the latter part of the growing season (Packman and Philpotts, 1955). Experience at the Geographical Branch and elsewhere (Philpotts, 1957) has shown that, using photographs taken at various scales and flown at times outside the growing season, the separation between grain and hay is not reliable. Consequently in many areas it has been necessary to show Categories 4 and 5 as complexes, with the proportion of each category based on figures derived from the 1961 Census of Agriculture.

LIMITATIONS OF THE CLASSIFICATION

For anyone using maps embodying the land-use classification it is important to realize what the maps do *not* show, as well as what they *do* show. The maps do not purport to be all-inclusive in their description of the present position. They do not reveal any of the socio-economic factors intimately related to use of the land, such as size of farm units or type of land tenure. Alone they reveal very little about land capability. Prime agricultural land may be covered by woodland; this fact will emerge only when the present land-use map is compared with the soil capability map. Nor do the maps reflect degrees of productivity within categories; the lush pastures of the lower Fraser valley in British Columbia appear in the same category as the weedy timothy fields of the part-time farmers along the margin of the Canadian Shield. The present land-use classification is simply an attempt to determine the area and show the location of the major uses of land across the country.

The major defect in the classification is one that is common to most present land-use classifications. It relates to the nature of the last four categories. In reality these are not "use" categories, but rather, "cover-type" categories. Thus, the actual use of woodland may be for grazing, or much of the unimproved pasture land may have no use at all—as in the case of idle land held for speculation around the edges of cities, or abandoned farmland reverting to bush along the margins of the Canadian Shield. In many cases, the determination of actual use in these categories could only be accomplished through extensive field work and interviewing. As this is not feasible if the maps are to be completed within the allotted time, it must be accepted that for some categories no specific use can be assigned with any degree of certainty.

PREPARATION OF THE MAPS

Preparation of the land-use maps is quite rapid. Mapping is done on the standard 1:50,000 topographical sheets, which show roads, rivers, railways, wooded areas, buildings and civil boundaries. After familiarizing himself with the background information that has been assembled for the area and after plotting on the base the data available from other sources, such as forest inventory maps and university thesis maps, the interpreter plots directly from air photographs to the base map, transferring the data by eye. Category boundaries are drawn using a pencil and the category is shown by a letter. Any problem areas that require further checking are noted and dealt with at a later date. Category boundaries along the margins of the sheet are checked against adjacent sheets to ensure that a constant standard of interpretation is being maintained. One interpreter can complete a 1:50,000 half-sheet in about three days.

After the interpretation of a sheet is complete, a transparent cronaflex base is placed over it, and the category designations and boundaries are traced off in ink. At this stage compilational errors made by the interpreters can be detected. When inked in, the map is ready for use as computer input data. In addition, use of the transparent cronaflex base permits rapid reproduction of copies of the map by means of the ozalid process; these copies can then be hand-coloured for administrative purposes.

PROGRESS ON THE PROJECT

By December 31, 1964, a nation-wide system of present land-use classification had been agreed upon, a manual outlining the detailed application of the classification had been prepared, and work had begun on the project in eight provinces. At the Geographical Branch more than 400 1:50,000 half-sheets were in varying stages of completion. The Geographical Branch expected to complete the mapping in eastern Canada by March 31, 1967. In western Canada, mapping had begun in Alberta and British Columbia, under the direction of the departments of geography at the University of Alberta (Edmonton) and the University of Victoria, and mapping was expected to begin in Manitoba and Saskatchewan early in 1965.

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THE FUNCTIONAL STRUCTURE OF CANADIAN CITIES: A CLASSIFICATION OF CITIES

J. W. Maxwell

ABSTRACT

The functional profiles of the major cities in Canada have been characterized in order to obtain an overview of the Canadian urban scene. Each city's dominant function, its distinctive functions, and its degree of functional specialization have been determined to achieve this end. These three features are defined in terms of basic employment which is calculated by applying the "minimum requirements method" of city analysis as developed by Ullman and Dacey. The overview gained indicates that a fundamental difference in functional character exists between the cities in the densely populated St. Lawrence Lowlands and southern Ontario—the heartland—and the cities in the remainder of Canada—the periphery. Heartland cities are more specialized and emphasize manufacturing to a greater degree than do the cities in the periphery. The latter, except for a few resource-oriented manufacturing centres, are diversified and have an important involvement with functions associated with distance such as wholesale trade and transportation. The Canadian heartland and periphery differ in historical, economic, and to some degree, in cultural development. That their cities reflect these differences is a reasonable and not unexpected conclusion.

RÉSUMÉ

L'auteur a trouvé la silhouette fonctionnelle du caractère propre des grandes villes du pays, afin de donner une idée générale de leur aspect extérieur. A cette fin, il a déterminé le caractère dominant de chacune d'elles, ses traits particuliers et le degré de son caractère spécial. Ces trois catégories de caractères sont définies en fonction de l'emploi fondamental, calculé par la méthode d'étude urbaine Ullman et Dacey, celle qui tient compte des besoins minimums. L'idée générale obtenue indique que le caractère propre diffère foncièrement suivant qu'il s'agit des villes des basses terres du St-Laurent et du Sud de l'Ontario—le coeur du pays—ou de celles du reste du Canada—la périphérie. Les premières ont un caractère plus spécialisé que les secondes, et l'industrie manufacturière y a pris plus d'importance que dans les autres. Ces dernières, sauf dans quelques grandes villes qui tendent à dépendre des ressources naturelles, ont une activité variée et sont liées dans une grande mesure à des caractères associés à la distance, par exemple le commerce en gros et les moyens de transport. Coeur et périphérie diffèrent quant à l'évolution historique, le développement économique et, jusqu'à un certain point, la culture. La conclusion raisonnable et non inattendue, semble-t-il, c'est que ces différences se révèlent dans les grandes villes des deux domaines.

INTRODUCTION

Geographers have long been interested in developing methods for classifying and comparing cities by function and specialization. Dickinson (1948, p. 231) reports that pioneer work was done as early as 1841 on the comparative study of towns as commercial centres. With the advent of modern tabulating machines which have made feasible the publishing of detailed statistics for very small units including cities of small populations, quantitative methods of classification have come to the fore. Harris (1964, p. 60) lists the many quantitative city classification studies that have been made since he and William-Olsson published the first such studies in 1943 (Harris, 1943; William-Olsson, 1943, in Alexandersson, 1956, p. 21). These studies have proven useful at the preliminary stage of investigation since they allow the important functions of many cities to be identified by broad categories in a rapid and inexpensive manner. Such studies "suggest different types of relationships which urban agglomerations may have to one another and to economic regions" (Harris, 1964, p. 60). They present an overview of the urban

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scene at the regional or national level. It is the purpose of this study to develop such an overview for the Canadian urban scene by studying the functional structure of the major cities in the nation.

CITIES STUDIED

All of the 106 incorporated urban centres in Canada that had 1951 populations of 10,000 and more were included in the study. The total number of cities was reduced to eighty by recognizing census metropolitan areas as individual cities and grouping other contiguous municipalities to form single units. The grouping of adjoining urban municipalities allows a better approximation of geographical centres to be obtained.

Unincorporated urban centres and cities with populations of less than 10,000 in 1951 were omitted because the necessary labour-force statistics are not published for them. Kirkland Lake (1951 population: 18,392) was the only large centre affected by this lack of data. Table I gives the population, regional location, and constituent municipalities or census metropolitan area of all cities studied. Figure 1 shows the city locations and the system of regions that was established for analytical purposes.

SOURCE MATERIAL

Canadian census labour-force statistics for place of residence classified by industry were utilized exclusively as source material (D.B.S., 1953). As data from the 1961 census were not yet available when the study was done (1963), it was necessary to use 1951 statistics. The use of somewhat dated source material was not thought to be a serious limitation since the emphasis of the project was on methodology as well as on fact-finding. The results reveal the character of the functional profiles of the major Canadian cities at a particular point in time.

FUNCTIONAL CATEGORIES

City "functional structure" was equated to city "employment structure" as it was thought that the activities in which a city's people earn their living provide good indicators of city functions. The terms "city activity" and "city function" were taken to be synonymous. The city functions recognized consist of groupings of census industrial categories. The 1951 *Census of Canada* breaks down the services performed by the labour force into twelve industry divisions which are further broken down into major groups. The first column of Table II lists all census industry divisions and major groups that were relevant for the study. The second column of the table presents the city functional categories derived from the census categories. The functional classes represent broad groups in the employment structure of the city. Although highly aggregated, these categories are sufficiently detailed to distinguish in reasonably specific terms the functional character of cities. Also, by using these particular categories, it was possible to use key findings of an American study (Ullman and Dacey, 1960) in determining the outstanding characteristics of cities.

METHOD OF ANALYSIS

BASIC EMPLOYMENT

Basic employment—that part of total city employment engaged in activities that produce goods and services for markets outside the city—was used when characterizing city functional structures. It is the basic employment that identifies the raison d'être of a city and reveals the functional relationships that exist between the city and its hinterland (Alexander, 1954). To calculate each city's basic employment in the respective functions, a technique developed by Ullman and Dacey (1960), termed the "minimum requirements method," was used. These analysts were able to produce:

> "... a quantitative statement which closely approximates the minimum percentage of a labour force required in various sectors of its economy to maintain the viability of an urban area. The employment in an urban area which is greater than this minimum requirement is called excess employment ... the excess employment approximates the export or basic employment." (p. 176).

Minimum requirement values for selected functions were determined empirically by Ullman and Dacey for American cities of various size classes. These values were given as percentages of total city labour force. They found, as had earlier investigators (Morrissett, 1958), that the minimum requirement values varied with city size. As city size increases, the minimum employment in the various functions required to keep the city viable also increases; however, the rate of this increase differs among functions. By plotting the empirically derived values for city minimum requirements in functions against the logarithms of the city population values, Ullman and Dacey found that the plotted points closely fit a straight line. Using these data, they were able to develop linear regression equations that allow expected minimum requirement values

Table I

Cities Examined: Population, Location, and Municipal Constituents

City[a]	Population (1951)	Location	Component Municipalities or Census Metropolitan Areas (C.M.A.)
Arvida	11,078	northern periphery	Arvida
Barrie	12,514	heartland	Barrie
Belleville	19,519	"	Belleville
Brandon	20,598	western periphery	Brandon
Brantford	36,727	heartland	Brantford
Brockville	12,301	"	Brockville
Calgary	139,105	western periphery	Calgary C.M.A.
Charlottetown	15,887	eastern periphery	Charlottetown
Chatham	21,218	heartland	Chatham
Chicoutimi	23,216	northern periphery	Chicoutimi
Cornwall	16,899	heartland	Cornwall
Drummondville	14,341	"	Drummondville
Edmonton	173,075	western periphery	Edmonton C.M.A.
Edmundston	10,753	eastern periphery	Edmundston
Fredericton	16,018	eastern periphery	Fredericton
Galt	19,207	heartland	Galt
Glace Bay	25,586	eastern periphery	Glace Bay
Granby	21,989	heartland	Granby
Grand'Mère	11,089	"	Grand'Mère
Guelph	27,386	"	Guelph
Halifax	133,931	eastern periphery	Halifax C.M.A.*
Hamilton	259,685	heartland	Hamilton C.M.A.
Joliette	16,064	"	Joliette
Jonquière	21,618	northern periphery	Jonquière
Kingston	33,459	heartland	Kingston
Kitchener-Waterloo	56,858	"	Kitchener, Waterloo
Lethbridge	22,947	western periphery	Lethbridge
London	121,516	heartland	London C.M.A.*
Magog	12,423	"	Magog
Medicine Hat	16,364	western periphery	Medicine Hat
Moncton	27,334	eastern periphery	Moncton
Montreal	1,395,400	heartland	Montreal C.M.A.
Moose Jaw	24,355	western periphery	Moose Jaw
New Waterford	10,423	eastern periphery	New Waterford
Niagara Falls	22,874	heartland	Niagara Falls
North Bay	17,944	northern periphery	North Bay
Orillia	12,110	heartland	Orillia
Oshawa	41,545	"	Oshawa
Ottawa	281,908	"	Ottawa C.M.A.
Owen Sound	16,423	"	Owen Sound
Pembroke	12,704	"	Pembroke
Penticton	10,548	western periphery	Penticton
Peterborough	38,272	heartland	Peterborough
Fort William-Port Arthur	66,108	western periphery	Port Arthur, Fort William
Prince Albert	17,149	western periphery	Prince Albert
Quebec	274,827	heartland	Quebec C.M.A.

(continued over page)

Table I—concluded

Cities Examined: Population, Location, and Municipal Constituents

City[a]	Population (1951)	Location	Component Municipalities or Census Metropolitan Areas (C.M.A.)
Regina	71,319	western periphery	Regina
Rimouski	11,565	eastern periphery	Rimouski
Rouyn	14,633	northern periphery	Rouyn
St. Catharines	37,984	heartland	St. Catharines
St. Hyacinthe	20,236	"	St. Hyacinthe
St. Jean	19,305	"	St. Jean
St. Jérôme	17,685	"	St. Jérôme (Terrebonne)
St. John's	67,749	eastern periphery	St. John's C.M.A.
St. Thomas	18,173	heartland	St. Thomas
Saint John	78,337	eastern periphery	Saint John C.M.A.*
Sarnia	34,697	heartland	Sarnia
Saskatoon	53,268	western periphery	Saskatoon
Sault Ste. Marie	32,452	northern periphery	Sault Ste. Marie
Shawinigan	26,903	heartland	Shawinigan
Sherbrooke	50,543	"	Sherbrooke
Sorel	14,961	"	Sorel
Stratford	18,785	"	Stratford
Sudbury	42,410	northern periphery	Sudbury
Sydney	31,317	eastern periphery	Sydney
Thetford Mines	15,095	heartland	Thetford Mines
Timmins	27,743	northern periphery	Timmins
Toronto	1,117,470	heartland	Toronto C.M.A.
Trail	11,430	western periphery	Trail
Trenton	10,085	heartland	Trenton
Trois-Rivières	64,741	"	Trois Rivières; Cap-de-la-Madeleine
Truro	10,756	eastern periphery	Truro
Valleyfield	22,414	heartland	Valleyfield (Salaberry-de)
Vancouver	530,728	western periphery	Vancouver C.M.A.
Victoria	104,303	western periphery	Victoria C.M.A.*
Victoriaville	13,124	heartland	Victoriaville
Welland	15,382	"	Welland
Windsor	157,672	"	Windsor C.M.A.
Winnipeg	354,069	western periphery	Winnipeg C.M.A.
Woodstock	15,544	heartland	Woodstock

[a]Geographical rather than legal cities have been used where possible. Census Metropolitan Areas are considered as single cities, as are clusters of contiguous municipalities.

*C.M.A. for which unpublished data were supplied by the Dominion Bureau of Statistics.

NOTE: Certain urban complexes have not been recognized because the component cities have highly individualistic and often contrasting functional profiles. By reporting these cities separately, their outstanding functional characteristics are fully recognized. Such is the case for the cities forming the urban complexes in: (1) the Saguenay Valley (Chicoutimi, Arvida, Jonquière), (2) Cape Breton Island (Sydney, Glace Bay, New Waterford) and (3) the St. Maurice Valley (Shawinigan and Grand'Mère).

for functions to be calculated for cities of all sizes. Once a city's minimum requirement values for functions are known, the excess employment can be calculated. This excess employment can be taken as a good approximation of basic employment.

EXCESS (BASIC) EMPLOYMENT IN CANADIAN CITIES

The Ullman-Dacey regression equations, where applicable, were used to determine the minimum requirement values and the excess employment in Canadian cities. Where these equations were not

Table II

Census Industrial Categories and City Functional Categories Used in the Study

Census Industry Divisions and Major Groups significant to the study[a]	City Functions recognized in the study
Agriculture	Omitted
Forestry and Logging	Omitted
Fishing and Trapping	Omitted
Mining, Quarrying and Oil Wells	Extraction
Manufacturing	Manufacturing
Electricity, Gas, and Water	Public Utilities
Construction	Construction
Transportation, Storage, Communication	Transportation
Trade	
Wholesale Trade	Wholesale Trade
Retail Trade	Retail Trade
Finance, Insurance, and Real Estate	Finance, Insurance and Real Estate
Service	
Community Service[b]	Community Service
Government Service[c]	Government Service
Recreation	Recreation
Business Service[d]	Business Service
Personal Service[e]	Personal Service
Not Stated	Omitted

[a]Dominion Bureau of Statistics, *Ninth Census of Canada: 1951. Labour Force*, Vol. IV, Tables 17 and 21 (Ottawa: Queen's Printer, 1953).

[b]"Community Service" includes labour force in education, health, religion and welfare work. Includes government personnel and persons employed by private agencies doing work in health, welfare and educational fields.

[c]"Government Service" includes labour force employed in work peculiar to public service only. It includes municipal, provincial and federal government employees and all military and post office personnel.

[d]"Business Service" includes labour force employed in accounting, advertising, engineering and scientific services, labour and trade organizations, law, and other business services.

[e]"Personal Service" includes labour force employed in barbering and hairdressing, dry cleaning and laundry, restaurants, motels and hotels, private households, undertaking, photography, and other personal service.

Table III

Minimum Percentages Employed in Canadian Cities of Varying Size Classes, 1951

Function	Cities (population in thousands) 10.0-19.9 (35 cities)	20.0-29.9 (15 cities)	30.0-99.9 (17 cities)	100 & over (13 cities)
	per cent of city urban labour force			
Extraction	0.0	0.0	0.0	0.0
Manufacturing	2.7	5.2	11.8	12.4
Public Utilities	0.4	0.5	0.6	0.8
Construction	1.8	3.3	4.0	5.8
Transportation	2.4	3.2	3.6	5.1
Wholesale Trade	0.4	1.0	1.5	3.0
Retail Trade	4.2	8.3	9.1	10.3
Finance, Insurance & Real Estate	1.1	1.1	1.7	2.5
Community Service	4.7	5.3	5.1	5.7
Government Service	1.9	1.6	2.5	3.0
Recreation	0.2	0.4	0.4	0.4
Business Service	0.2	0.3	0.6	1.2
Personal Service	4.4	4.0	4.2	5.4
TOTAL	24.4	34.2	45.1	55.6

SOURCE: Calculated from the Ninth *Census of Canada*, 1951.

FIGURE 1. Canadian cities of 10,000 and more population, 1951.

applicable to the Canadian situation, similar equations based on Canadian data were used. This was the case for six of the thirteen functions. For one function, extraction, a regression equation was not required because the empirically derived minimum requirement values do not vary with changes in city size for this particular function.

The regression equations derived from the Canadian data were developed by calculating the percentage of each city's urban labour force* in each of the functions, and grouping the cities into four arbitrarily determined groups on the basis of population. For every function the minimum percentage figure in each city group was noted (Table III). These values were considered to be empirical minimum requirements. They were plotted against the logarithms of the appropriate city population values and regression lines were fitted to them. Expected minimum requirement values for cities of any size could then be read off the regression lines.

Comparison of the regression lines based on Canadian data with the equivalent Ullman-Dacey lines showed that the latter gave lower minimum requirement values at the high-population levels. This situation arises, it is thought, because in Canada there are few very large cities and they are widely dispersed. None of these cities are units in well-integrated "city systems" such as the Manufacturing Belt of the United States where cities the size of the largest Canadian centres are clustered together, and where exchange among centres reaches large proportions. In the city of the system, concentration on one or few functions is possible. Only the minimum activity necessary to keep the city viable needs to be maintained for other functions. In contrast, the non-system city must be more self-sufficient because it cannot depend to the same degree on other cities for its needs, and because it must be much more concerned with the requirements of its rural hinterland. This latter situation is not conducive to the maintenance of only minimum requirements in functions. Although "city systems" do exist for medium sized cities in Canada—for example, the city cluster focused on Toronto in southern Ontario—they do not exist for the very large cities in the country. For this reason, the possibility of finding only the minimum activity necessary to keep a city viable is remote for these large centres.

The Ullman-Dacey equations were given priority over the Canadian based ones because the United States with its large number of cities, provides a more favourable area from which to draw values representative of "actual" minimum requirements. It also contains "city systems" with cities the size of the largest Canadian centres. Differences in the urban socio-economic environment of Canada and the United States are not considered to be of sufficient significance to invalidate the application of American values to the Canadian situation. The same economic functions are performed, using similar technology, in the cities of both countries and the social mores of urbanites are not greatly different in the two nations. Figure 2 shows the regression lines used in determining the expected minimum requirements for the functions.

CHARACTERIZATION OF CITY FUNCTIONAL STRUCTURES

Three characteristics were used to typify city functional structures: the city's dominant function, its distinctive functions, and its degree of functional specialization. The dominant function of a city is defined as the activity having the largest share of the city's total excess employment. A distinctive function is defined as an activity whose share of total excess employment in a city greatly exceeds the share it usually has in most cities. City specialization is given by an index based on the relationship of a city's distribution of total excess employment among functions to its distribution of minimum requirement employment among the functions.

DOMINANT AND DISTINCTIVE FUNCTIONS

By recognizing two types of functions—dominant and distinctive functions—two kinds of functional importance are considered. Functions are rated in terms of their importance in a city's functional structure relative to the importance of the other functions in the city's structure when determining the dominant activity of a city. When identifying a city's distinctive functions, activities are rated in terms of their importance in a city's functional profile relative to their importance in the functional profiles of all cities studied.

When identifying the dominant functions in cities, two classes of manufacturing dominance were recognized: "Manufacturing I" and "Manufacturing II." This was done because this function has the largest share of excess employment in so

*Total city labour force excluding the labour force in the "Agriculture", "Forestry and Logging", "Fishing and Trapping," and "Not Stated" categories of the 1951 Census of Canada industrial classification. Employment in these categories is very insignificant for urban areas. For practical purposes, urban labour force can be equated to total city labour force.

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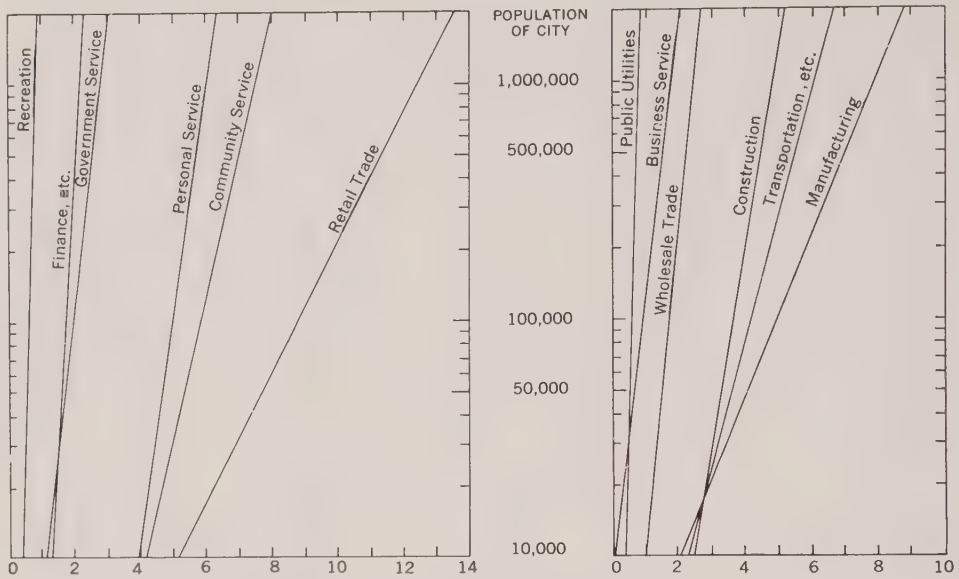

All equations are of the form: log y = a + bx; where y is city population and x is the "expected minimum requirement value" The y-intercept and the slope of the equations are:

FUNCTION	y- INTERCEPT (a)	SLOPE (b)	FUNCTION	y- INTERCEPT (a)	SLOPE (b)
Manufacturing [1]	3.2200	0.3526	Finance, etc. [1]	0.8338	2.3162
Public Utilities [2]	1.6145	5.5067	Community Service [2]	1.5092	0.5964
Construction [1]	1.7307	0.8861	Government Service [1]	2.4616	1.2651
Transportation [2]	2.7558	0.5255	Recreation [1]	1.9892	5.0020
Wholesale Trade [1]	2.2731	1.5671	Business Service [2]	3.8772	1.2576
Retail Trade [2]	2.6033	0.2731	Personal Service [2]	0.2929	0.9572

[1] Equation after Ullman and Dacey

[2] Equation based on the "four-class" city-grouping scheme of Canadian cities.

FIGURE 2. Regression lines used to determine expected minimum requirements for functions.

many cities. Included in the first class are all cities where 50 per cent or more of a city's excess employment is accounted for by manufacturing. In the second class are all cities where manufacturing is dominant, but accounts for less than 50 per cent of the city's excess employment.

Four classes of distinctive functions were recognized. The classes were defined in terms of standard deviation values of excess employment above the mean value of excess employment for an activity. For each function, Class I includes all cities whose value of excess employment for the function under consideration is equal to the mean value of excess employment for the function, plus a value of at least two standard deviations above the mean. Class II includes all cities whose values of excess employment for the function exceed the mean by between one and two standard deviations, and Class III includes all cities whose excess employment value for the function is between the mean and one standard deviation above the mean. Class IV includes all cities where excess employment values for the function are below the mean. Table IV shows the values determining the classes of importance for each function.

Cities were rated in each function in terms of the classes of "distinctiveness." An activity was considered "distinctive" in the functional structure of a city when the city qualified for one of the first three classes. Cities have as many

Table IV

Values of Excess Employment for Determining Classes of Functional Importance

Function	Mean value of excess employment	Standard deviation of excess employment	Class IV (mean value of excess employment)	Class III (between mean value and one standard deviation above the mean)	Class II (between one and two standard deviations above the mean)	Class I (over two standard deviations above the mean)
			per cent of city urban labour force			
Extraction	3.76	12.49	< 3.8	3.8 –16.2	16.3 –28.7	28.8 +
Manufacturing	30.91	18.25	< 30.9	30.9 –49.2	49.3 –67.4	67.5 +
Public Utilities	1.04	1.01	< 1.0	1.0 – 2.0	2.1 – 3.1	3.2 +
Construction	3.85	2.28	< 3.8	3.8 – 6.1	6.2 – 8.4	8.5 +
Transportation	5.56	5.11	< 5.6	5.6 –10.7	10.8 –15.8	15.9 +
Wholesale Trade	2.63	2.34	< 2.6	2.6 – 5.0	5.1 – 7.3	7.4 +
Retail Trade	5.52	2.91	< 5.5	5.5 – 8.4	8.5 –11.3	11.4 +
Finance, etc.	1.22	0.92	< 1.2	1.2 – 2.1	2.2 – 3.1	3.2 +
Community Services	4.23	3.63	< 4.2	4.2 – 7.9	8.0 –11.5	11.6 +
Government Service	5.06	6.31	< 5.1	5.1 –11.4	11.5 –17.7	17.8 +
Recreation	0.15	0.14	< 0.15	0.15– 0.29	0.30– 0.43	0.44 +
Business Service	0.65	0.81	< 0.65	0.65– 1.46	1.47– 2.27	2.28 +
Personal Service	2.63	1.74	< 2.6	2.6 – 4.4	4.5 – 6.1	6.2 +

distinctive activities as they have excess employment values qualifying them as being of Class I, II, or III in "distinctiveness." A function was not considered "distinctive" in a city when the city qualified only for a Class IV rating.

CITY FUNCTIONAL SPECIALIZATION

A procedure frequently used in determining the degree of functional specialization of cities is to compare the functional structure of individual cities with an idealized functional profile representing what is thought to be a balanced profile or a situation of minimum specialization (Florence et al., 1943; Rodgers, 1957). The city's degree of specialization is then given by the deviation of its functional profile from the model. The problem has been to develop meaningful models representative of a balanced structure.

In this study a specialization index developed by Ullman and Dacey (1960, p. 189) which utilizes the minimum requirement values for functions was adopted. These analysts have used the distribution of a city's total minimum requirement employment among the functions as a model of a balanced structure, that is, the case of minimum specialization. If the city's excess employment is distributed among the functions in the same proportions as is the minimum requirement employment, the case of least specialization is considered to exist. City specialization is thought to increase with increasing deviation of the city's excess employment distribution from the distribution of the city's minimum requirement employment among functions.

Ullman and Dacey designed their index so that large deviations of the excess employment distribution from the distribution of minimum requirement employment are accentuated. Their formula for determining the index is:

$$S = \Sigma_i \left[\frac{(P_i - M_i)^2}{M_i} \right] \div \frac{(\Sigma_i P_i - \Sigma_i M_i)^2}{\Sigma_i M_i}$$

where: "S" is the index of specialization, "i" refers to each of the thirteen functions, "P" to the percentage of city labour force employed in each of the "i" functions, "M_i" the expected minimum requirement value for each function, and "Σ_i" the sum of all the functions.

An index value of unity indicates that the excess employment of the city is distributed among the functions in the same proportions as is the city's minimum requirement employment. This is the case of minimum specialization. As the value of the index increases, specialization is considered to increase.

When determining the specialization indices of Canadian cities, one modification of the Ullman-Dacey system was made. The formula for the index operates satisfactorily as long as the expected minimum requirement value for a function is not zero. In the case of extraction, this value is zero for all cities. To overcome this problem, an arbitrary value of 0.01 per cent of city labour force was assigned as the expected minimum requirement value for this function. By using 0.01 rather than zero, the high specialization typical of mining centres is reflected by the index and, at the same time, the arbitrarily selected value (0.01) is small enough to avoid serious distortion of the index values for non-extraction centres.

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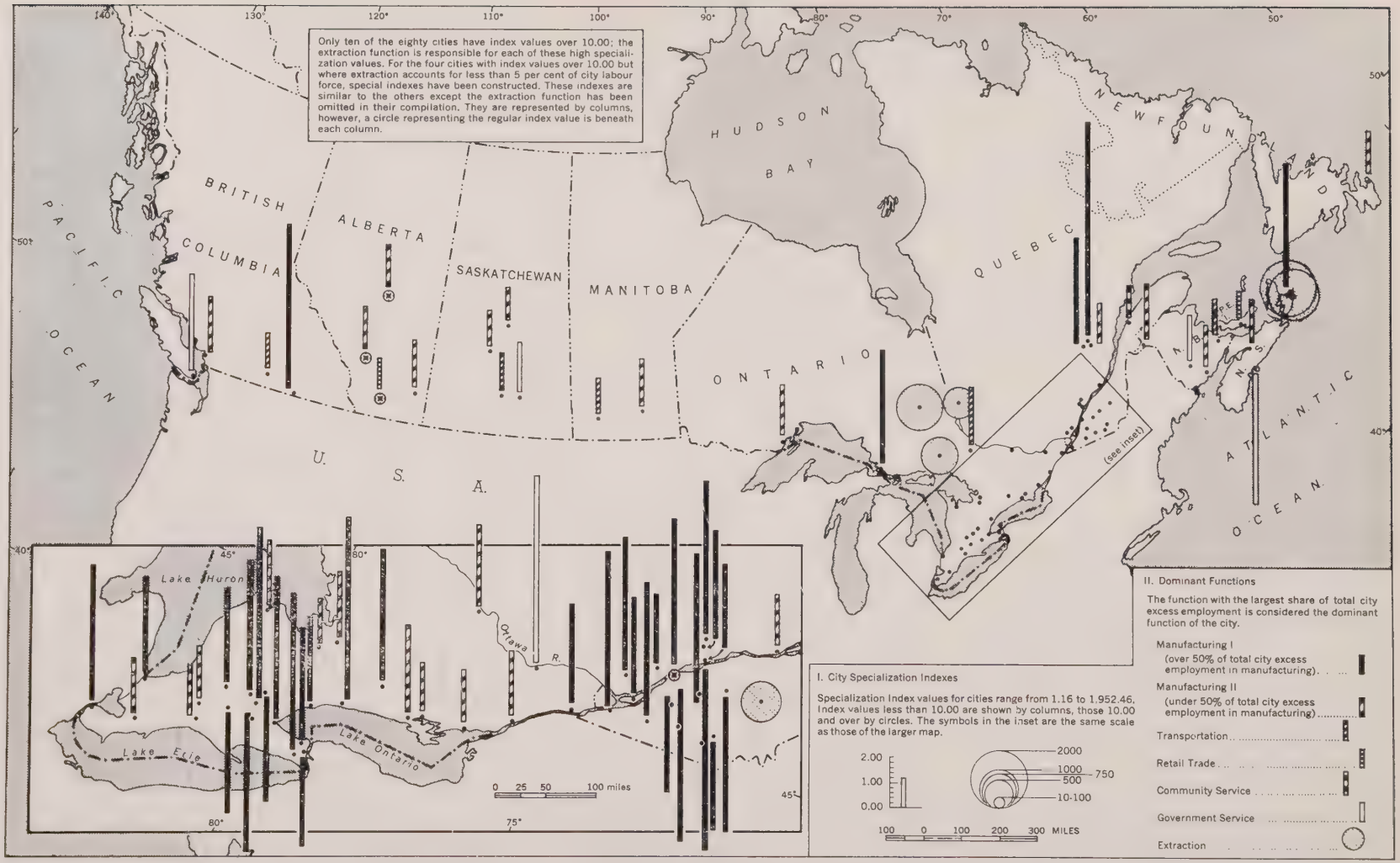

Only ten of the eighty cities have index values over 10.00; the extraction function is responsible for each of these high specialization values. For the four cities with index values over 10.00 but where extraction accounts for less than 5 per cent of city labour force, special indexes have been constructed. These indexes are similar to the others except the extraction function has been omitted in their compilation. They are represented by columns, however, a circle representing the regular index value is beneath each column.
HUDSON BAY
NEWFOUNDLAND
BRITISH COLUMBIA
ALBERTA
SASKATCHEWAN
MANITOBA
ONTARIO
QUEBEC
PACIFIC OCEAN
ATLANTIC OCEAN
U. S. A.
(see inset)
Lake Huron
Ottawa R.
Lake Erie
Lake Ontario
0 25 50 100 miles
I. City Specialization Indexes
Specialization Index values for cities range from 1.16 to 1,952.46. Index values less than 10.00 are shown by columns, those 10.00 and over by circles. The symbols in the inset are the same scale as those of the larger map.
2.00
1.00
0.00
2000
1000
500
750
10-100
100 0 100 200 300 MILES
II. Dominant Functions
The function with the largest share of total city excess employment is considered the dominant function of the city.
Manufacturing I
(over 50% of total city excess employment in manufacturing)
Manufacturing II
(under 50% of total city excess employment in manufacturing)
Transportation
Retail Trade
Community Service
Government Service
Extraction

FIGURE 3. Dominant functions and functional specialization of Canadian cities.

THE RESULTS OF ANALYSIS

The dominant and distinctive functions and specialization index of each city studied are presented in the appendix. While of interest in themselves, the distribution patterns that can be derived from these data are of greater geographical significance. Maps showing the distributions of functions as dominant and distinctive activities in cities and of city specialization values were constructed. The distribution patterns were examined in terms of the Canadian heartland—the densely populated St. Lawrence Lowlands and southern Ontario—and the periphery of Canada—the remainder of the country. This regional framework is useful when analyzing city functional character at the national level because the distribution of cities within the two regions differs so greatly.

The patterns of functional dominance and specialization given in Table V and Figure 3 show in a dramatic way the overwhelming importance of manufacturing in city functional structures. This function is dominant in sixty-one of the eighty cities. Only five other functions register as dominant activities. Extraction is dominant in six centres, transportation in five, government service in five, retail trade in two, and community service in one.

Although manufacturing is almost ubiquitous as a dominant function, it achieves an especially important position in the functional profiles of heartland cities. Even within the heartland, there is a high concentration of manufacturing dominance. All but two of the heartland cities with ratings of "Manufacturing I" are found in the

Table V

Dominant Functions and Specialization Indexes of Canadian Cities

City Periphery: Heartland	Specialization Index	Dominant Function
Charlottetown	1.16	Retail Trade
(Lethbridge*)	1.25	" "
Rimouski	1.36	Community Service
Prince Albert	1.40	Manufacturing II
Brandon	1.41	Transportation
Penticton	1.44	"
Saskatoon	1.51	Manufacturing II
Moncton	1.55	Transportation
Moose Jaw	1.56	"
Saint John	1.67	Manufacturing II
Chicoutimi	1.72	"
St. John's	1.75	"
Truro	1.77	"
(Calgary*)	1.77	"
(Edmonton*)	1.80	"
Fredericton	1.86	Government Service
Barrie	1.87	Manufacturing II
Medicine Hat	1.97	"
Winnipeg	2.00	"
Belleville	2.01	"
Fort William-Port Arthur	2.08	"
Regina	2.09	Government Service
Quebec	2.11	Manufacturing II
St. Thomas	2.14	"
Kingston	2.17	"
London	2.17	"
Chatham	2.26	"
North Bay	2.35	Transportation
Edmundston	2.35	Manufacturing II
Vancouver	2.40	"
Brockville	2.71	"
Owen Sound	2.73	"
Orillia	2.74	"
Joliette	2.88	Manufacturing I
Pembroke	3.41	Manufacturing II
Toronto	3.51	Manufacturing I
Trois Rivières	3.52	"
Sherbrooke	3.61	"
Niagara Falls	3.62	"
Trenton	3.63	Manufacturing II
Stratford	3.87	Manufacturing I
Sarnia	3.90	"
Montreal	3.92	"
St. Hyacinthe	3.96	"
Victoria	4.01	Government Service
Woodstock	4.14	Manufacturing I
Cornwall	4.16	"
Gueiph	4.22	"
Jonquière	4.40	"
Shawinigan	4.53	"
St. Catharines	4.56	"
Sault Ste. Marie	4.70	"
Sydney	5.21	"
Kitchener-Waterloo	5.36	"
Windsor	5.41	"
Peterborough	5.42	"
Halifax	5.46	Government Service
St. Jean	5.55	Manufacturing I
St. Jérôme	5.56	"
Victoriaville	5.59	"
Brantford	5.67	"
Hamilton	5.88	"
(Sorel*)	6.05	"
Drummondville	6.24	"
Granby	6.28	"
Grand'Mère	6.34	"
Valleyfield	6.39	"
Welland	6.54	"
Trail	6.86	"
Galt	7.14	"
Oshawa	7.50	"
Magog	7.56	"
Ottawa	7.84	Government Service
Arvida	8.96	Manufacturing I
Sorel**	10.93	
Lethbridge**	11.69	
Edmonton**	14.96	
Calgary**	17.21	
Rouyn	612.92	Extraction
Sudbury	918.63	"
Thetford Mines	1139.76	"
Timmins	1400.66	"
Glace Bay	1697.89	"
New Waterford	1952.46	"

*The regular index value is very high because of the extraction function; this function, however, accounts for less than 5 per cent of city labour force. Because of this, a special index was constructed. It is similar to the regular index except that extraction has been omitted in its compilation.

**Normal specialization index values.

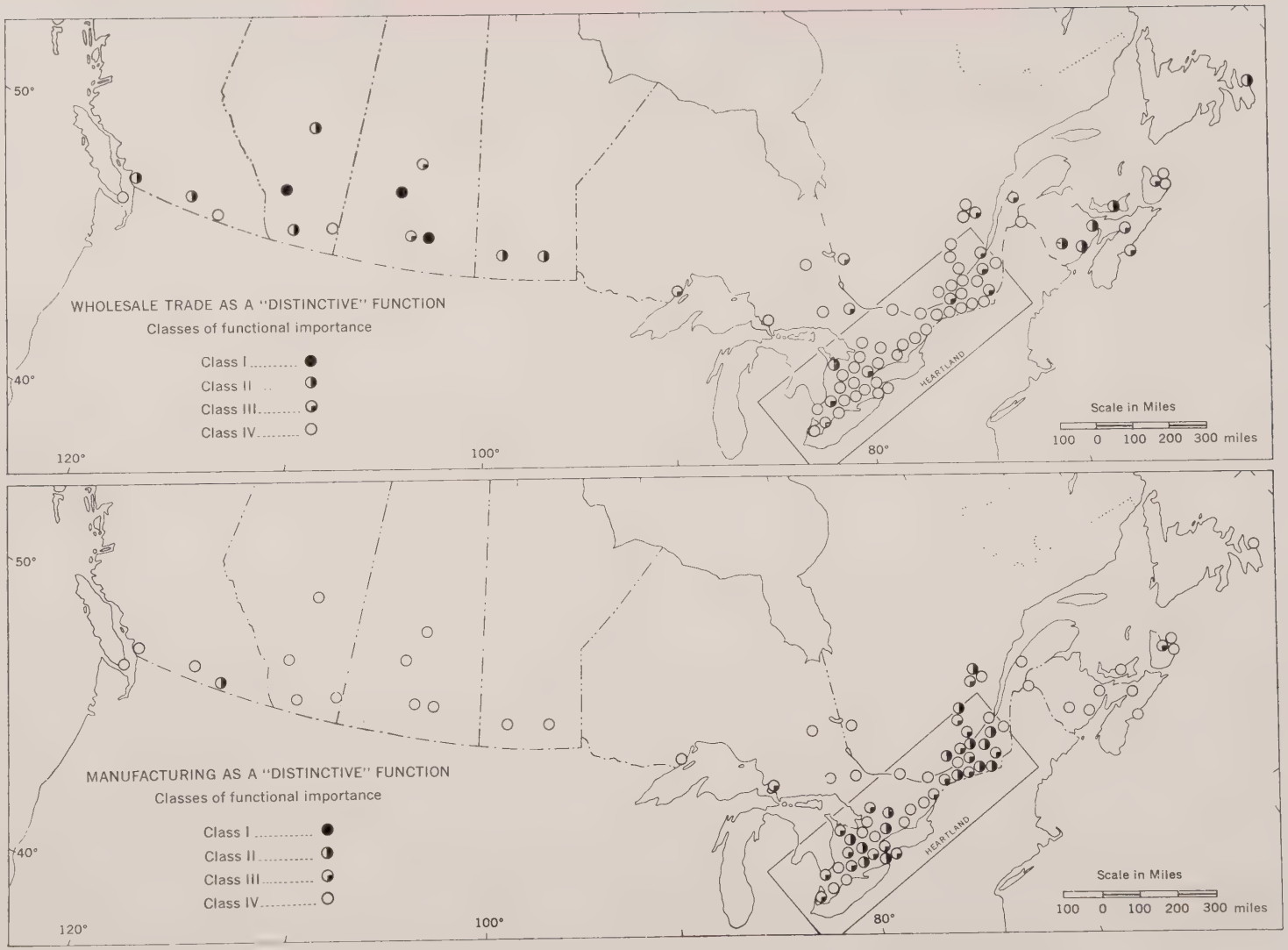


FIGURE 4. The distribution of wholesale trade and manufacturing as "distinctive" functions in Canadian cities.

city clusters focused on Toronto and Montreal respectively. These two nodes make up the manufacturing heart of Canada. Manufacturing in most of the heartland cities between and beyond the two city clusters, while still the dominant activity, has a much lower rate of importance.

Manufacturing generally plays a much less significant role as a dominant function in the profiles of periphery cities than in those of the heartland cities. All but two of the forty-five heartland cities have manufacturing as their dominant function. In contrast, just over one-third of the periphery cities are similarly characterized; the balance have transportation, retail trade or some other function as the dominant activity. In the periphery ratings of "Manufacturing I" are infrequent. Only five of the thirty-five cities in the periphery have such ratings. Further, there is a fundamental difference between "Manufacturing I" cities in the heartland and the periphery.

The heartland cities with ratings of "Manufacturing I" form basic units in fully integrated manufacturing regions where interaction among cities is very significant. High degrees of industrial linkage have developed among industries at both the intracity and intercity levels, and all types of industrial activity occur from blast furnace activity, to electronics manufacturing and food processing. Contrasting markedly with this situation is the position of the periphery "Manufacturing I" cities. They are few in number, have isolated locations, and usually have only one important industrial activity. These manufacturing cities also stand apart from the other periphery cities being highly specialized and not primarily concerned with servicing a rural hinterland. Although based on different activities, they have many traits in common with the extraction centres such as extremely high specialization rates and the tendency to be "one-industry towns." Without exception the periphery cities with "Manufacturing I" ratings are resource-oriented manufacturing centres such as Trail and Arvida.

Many of the cities with "Manufacturing II" ratings, both in the periphery and the heartland, are service or transport centres despite the high rating enjoyed in them by manufacturing as a dominant function. The fact that many of these centres are service centres suggests that the kind of manufacturing activity found in them will differ considerably from that of the "Manufacturing I" cities. It is thought that market-oriented manufacturing industries associated with the final stages of production will take up a proportionately larger share of city manufacturing activity in the service centres than in the specialized manufacturing cities ("Manufacturing I" centres) where industries associated with the earlier stages of production for both final and non-final markets will be relatively more important.

Industries that use local, ubiquitous materials such as water, whose products are highly perishable, where the manufacturing process involves weight gain, or where the size of market for one minimum-sized plant is small, will make up the bulk of the manufacturing activity in the service centres. Such industries as baking, soft drinks, and ice cream manufacturing are representative of this group. These are the kinds of industries that reinforce the central place functions of the city.

Because manufacturing enjoys a position of such overwhelming importance as a dominant activity, it tends to blanket many of the distinct and unique features in city functional profiles. This results in an almost uniform and colourless impression of city functional character. For this reason the distribution patterns of functions as distinctive activities need to be examined to determine the significant functional rôles of many cities. This is especially true when manufacturing is the dominant, but not a distinctive function in a city. This is the case in most cities with ratings of "Manufacturing II." If the most distinctive functions of this group of cities are examined the importance of the central place functions soon becomes apparent. Wholesale trade, finance, recreation and community service rank high as distinctive functions followed closely by retail trade, and government service. Transportation also ranks high as a distinctive function in some of these cities and serves to isolate those instances where cities owe their existence primarily to transport functions although having manufacturing as their dominant activity. Fort William-Port Arthur provides the classic example of a city that has built up an important manufacturing function based on a transport break-in-bulk point.

The relationship between the central place functions and manufacturing in the functional profiles of cities is clearly illustrated by Figure 4. Wholesale trade, a key central place function, is shown to have an almost unbroken high rating of distinctiveness in the periphery. In the heartland it appears distinctive only in the two major metropolitan cities, Toronto and Montreal, and in six other cities, four of which are outside the manu-

facturing nodes. Providing a marked contrast to this pattern is the distribution of manufacturing as a distinctive function. Manufacturing distinctiveness is almost completely restricted to the heartland cities of the manufacturing cores. Only in the resource-oriented manufacturing cities does the function appear distinctive in the periphery. Manufacturing, although dominant in many cities, both in the periphery and the heartland, is highly localized as a distinctive function. A major difference is seen to exist between the periphery and heartland in the relationship that wholesale trade and manufacturing have to one another in the functional profiles of the cities.

Further study of Table V and Figure 3 shows that a close association exists between city specialization, city location, and dominant functions. The highest rates of functional specialization are found in the extraction centres. These high rates are due primarily to the exclusive priority necessarily placed on resource location for this function. This feature often precludes the possibility of other city-forming activities emerging as important basic activities in extraction centres, resulting in extreme specialization rates. Next to the extraction centres, the most specialized group of cities are the "Manufacturing I" centres. These cities in the two manufacturing nodes of the heartland are highly specialized because the close proximity of cities to one another has allowed a high rate of city interdependence to develop. Concentration on one or few functions is possible for a city since it can rely on the other cities within the nodes for markets and many of its requirements. The resource-oriented manufacturing centres in the periphery are highly specialized for much the same reason as are the extraction centres. They are not located in areas with densely populated hinterlands where central place functions are required to a degree that would offset the manufacturing specialization. Further, because their industrial activity is concerned with one or few operations, rather than many as in the case of the cities in the manufacturing regions, the possibility of diversification developing even in the manufacturing component of their functional structures through industrial linkage is small.

Certain government centres also have high rates of specialization. The government function makes the national capital, Ottawa, one of the most specialized cities in the country. Without this activity the city would have a diversified structure and would be a relatively small service centre serving the lower Ottawa Valley. Victoria and Halifax also are highly specialized because of the existence of both administrative and military activities in their profiles. Like Ottawa, they would be relatively small regional centres with diversified structures if the government activity was not present. Most other cities that have important government functions have more diversified structures than the three cities cited because other functions are also important. This has a diversifying effect on their functional structure. Fredericton and Regina are examples of important government centres that have quite diversified profiles.

Functional diversification is greatest among the cities of the periphery where serving a large hinterland is the raison d'être of the city. Charlottetown, serving an insular agricultural hinterland, has the least specialized profile in the country. These periphery cities are closely followed, in terms of specialization, by heartland cities outside the manufacturing regions that act primarily as service centres. Specialization is slightly greater for these cities than their counterparts in the periphery because they are closer to the population centre of the nation and to the manufacturing nodes. The possibility of their receiving special activities such as the national headquarters of large firms is greater than it is for periphery cities. London, for example, is the principal service centre in southwestern Ontario. In addition, it is also an important financial and insurance centre on the national level.

These observations on dominant and distinctive functions, and city functional specialization suggest that a fundamental difference in functional character exists between the cities of the periphery and the heartland. The periphery cities, except for the resource-oriented manufacturing cities and the extraction centres, are less specialized and place a lower emphasis on manufacturing than do the heartland cities. Most periphery cities have an important involvement with functions associated with distance such as wholesale trade and transportation. The difference is illustrated most clearly in Figure 4 where wholesale trade is shown to be almost completely restricted to the periphery as a distinctive function. Manufacturing distinctiveness, in contrast, is shown to be limited to the heartland.

A review of the characteristics of wholesale trade and manufacturing is useful when examining the difference between heartland and periphery cities. Wholesale trade, while requiring the concentration of facilities and people for its performance, is essentially a function of space. It is

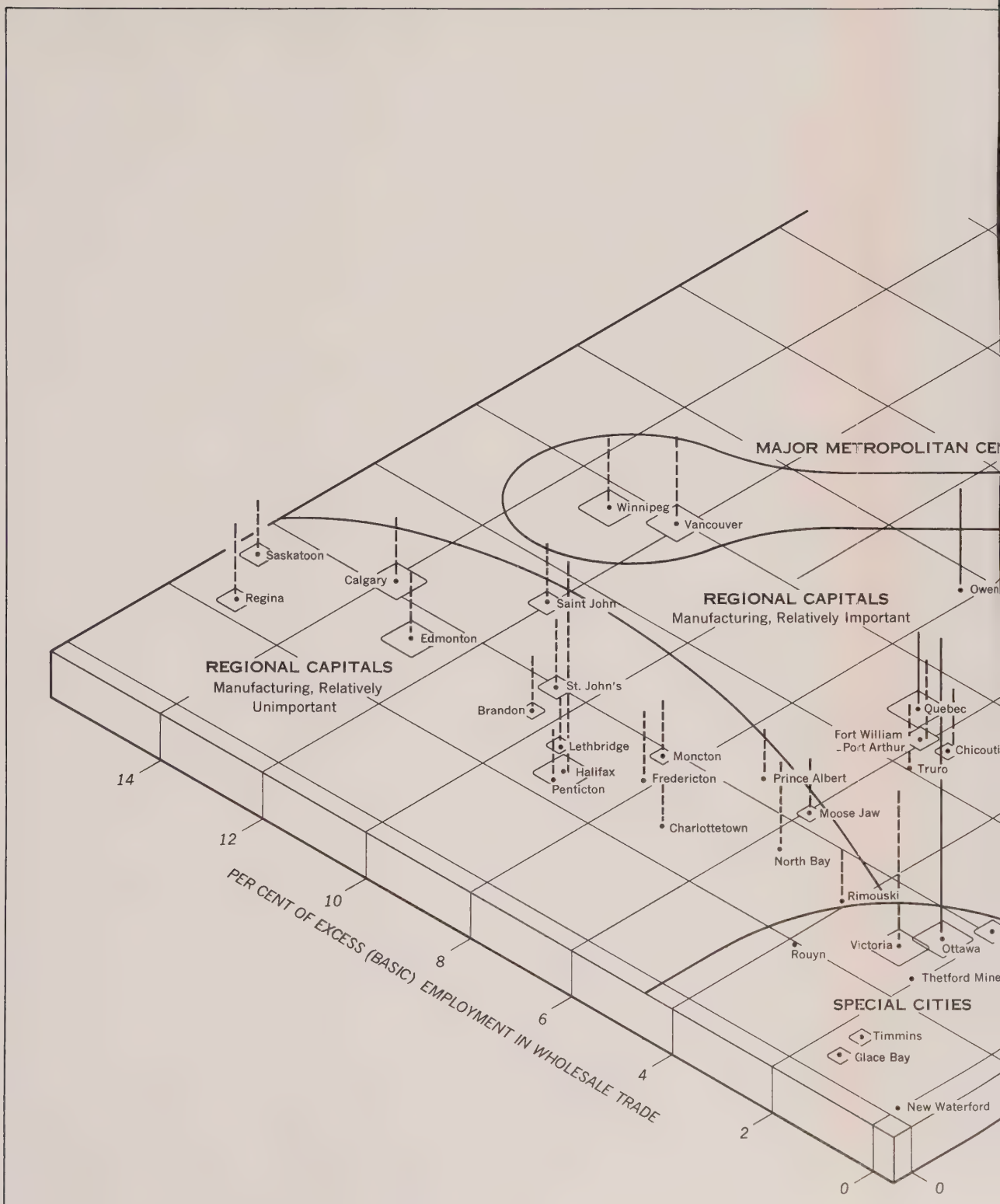
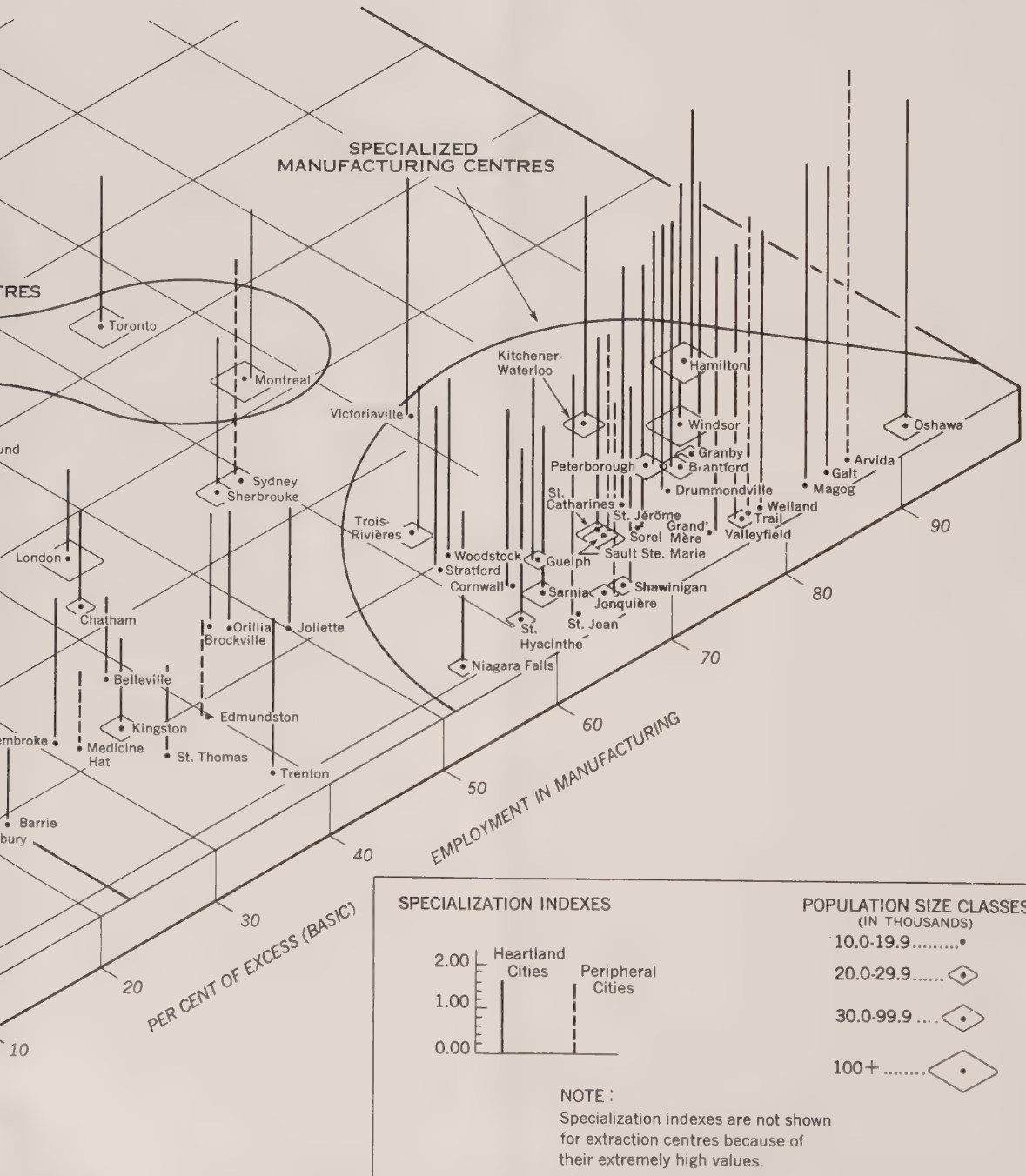


FIGURE 5. "City-t


SPECIALIZED
MANUFACTURING CENTRES
TRES
Toronto
Montreal
Victoriaville
Sydney
Sherbrooke
Trois-
Rivières
Kitchener-
Waterloo
Hamilton
Windsor
Granby
Peterborough
Brantford
Drummondville
St.
Catharines
St. Jérôme
Sorel
Grand'
Mère
Welland
Trail
Valleyfield
Oshawa
Arvida
Galt
Magog
Woodstock
Stratford
Cornwall
Guelph
Sault Ste. Marie
Sarnia
Jonquière
Shawinigan
St.
Hyacinthe
St. Jean
Niagara Falls
London
Chatham
Orillia
Brockville
Joliette
Belleville
Kingston
Edmundston
Medicine
Hat
St. Thomas
Trenton
Barrie
10
20
30
40
50
60
70
80
90
PER CENT OF EXCESS (BASIC)
EMPLOYMENT IN MANUFACTURING
SPECIALIZATION INDEXES
2.00
1.00
0.00
Heartland
Cities
Peripheral
Cities
POPULATION SIZE CLASSES
(IN THOUSANDS)
10.0-19.9
20.0-29.9
30.0-99.9
100+
NOTE :
Specialization indexes are not shown
for extraction centres because of
their extremely high values.

s" in Canada.

concerned with the collection, transfer, and distribution of goods. It can be expected therefore to reach its highest levels of relative importance in those areas where extensive activities are of prime importance. Such is the situation in the eastern and especially the western periphery. A very large proportion of the total "economic energy" generated in these areas is "consumed" in overcoming the great distances associated with extensive activities such as the wheat-production and ranching functions of the brown and dark-brown soil regions of the Great Plains. The cities in these areas reflect in their functional profiles this involvement with distance, and have the central place functions ranking high in their structures.

The manufacturing function, on the other hand, is focused on adding value to goods through their physical conversion. Economies that accrue through agglomeration and economies of scale tend to promote the concentration of manufacturing activity in areas where large populations and other manufacturing activities are located. Such locations provide easy access to market, allow specialization of production, provide more opportunities for substitution of inputs, and guarantee an ample labour supply. Only when the costs of assembling inputs is high in relation to total costs, when no substitutes are available, or when the weight loss is high in the manufacturing process will resource or input location factors override those factors favouring market-oriented locations.

Because of good accessibility to both the Old World and the United States, the presence of resources demanded on world markets, and the existence of a resource base favourable to agriculture, the heartland developed early as an area of population concentration. The existence, within a relatively small area, of energy resources, raw materials, and port facilities, together with the population concentration, satisfied the prerequisites required for manufacturing development. The heartland developed early as a manufacturing area in Canada and has become the centre of manufacturing activity for the nation. This is readily seen in the functional profiles of the heartland cities.

CITY TYPES IN CANADA

To achieve a summary view of the Canadian urban milieu and to illustrate further the basic differences existing between the functional positions of cities in the heartland and in the periphery, the cities were grouped into city-type classes. The classes were developed from a synthesis of the materials already presented. Five groups of cities were identified on the basis of the importance of wholesale trade, manufacturing, and degree of specialization in cities. Obviously, other city groups exist, but different criteria are required to identify them. The criteria selected and the groups recognized are considered to be the most significant ones at the macro level where the total Canadian urban milieu is being viewed. The percentages of a city's total excess employment in manufacturing and wholesale trade, respectively, were used as measures of importance for the two functions. These values for each city were plotted on an isometric graph (Figure 5), together with values of city population and functional specialization to facilitate the classifying of centres. So that other functions were not completely ignored, special note was made when individual cities within groups were known to have important functional positions that are not identified by the grouping criteria. In this way "transportation," "extraction," and "government" centres were identified.

Figure 5 reveals two familiar patterns: specialization generally increases with increases in the importance of manufacturing, and heartland cities are generally more specialized than the periphery cities. It also discloses several fairly distinct groups of centres. First, there are thirty-one cities with high to very high values of manufacturing importance, but with moderately low to low ratings for wholesale trade. Since these cities appear, for the most part, to have nearly minimal trading functions and, as a group, exhibit a high rate of specialization, they have been called "specialized manufacturing centres." All but four of these cities are located in the heartland. The four periphery cities are resource-oriented manufacturing centres where the nature of the manufacturing processes, and either: (1) the lack of a large, densely populated hinterland that would promote central place functions, or (2) the assumption of hinterland servicing by a nearby centre, have given rise to high specialization rates and a tendency for one industry to be dominant. In the heartland, it is the "specialized manufacturing centres" that make up the two manufacturing regions. While all these cities exhibit a high specialization in manufacturing, a fair degree of variation exists within the group. Oshawa, Galt and Magog, for example, present extreme cases of manufacturing specialization. These cities are almost juxtaposed to larger centres and are, in a sense, "specialized suburbs" or components of

"dispersed cities." Victoriaville and Trois Rivières, on the other hand, are important as regional capitals, although the central place functions are definitely secondary to manufacturing. The city with the lowest rating of manufacturing importance in the group, Niagara Falls, is a tourist centre as well as a manufacturing city. This feature is revealed by "distinctive" ratings for both the personal service (includes hotel, motel, and restaurant employment) and the recreation functions in this city.

Secondly, there is a group of eight cities that are very highly specialized, but have low rates of importance for both manufacturing and wholesale trade. Other functions, obviously, have the significant rôles in these cities. Because this feature (high specialization rates coinciding with low values in both manufacturing and wholesale trade) is characteristic of so few cities, these centres have been called "special cities." Included in this group are highly specialized government and extraction centres. The two most specialized Canadian cities, the mining centres of New Waterford and Glace Bay, have the lowest ratings of manufacturing importance in Canada. In some ways they resemble the highly specialized centres of Oshawa and Galt in that they are components of a "dispersed city." The two cities, with Sydney and smaller suburbs, make up the iron and steel complex of Cape Breton Island. The functional structures of these cities are well integrated with one another. The mining centre of Rouyn presents an interesting case because its value of wholesale trade is higher than for any other "special" city. It is an important distribution centre for settlement in the Clay Belt. Here is a case where a highly specialized extraction centre also acts as a service centre for surrounding areas.

A third group of cities is characterized by relatively high values of wholesale trade importance, low values of manufacturing importance, and generally low levels of specialization. Since city functional diversification and high ratings for trading functions are closely associated with hinterland servicing, the seventeen cities of this group have been called "regional capitals: manufacturing relatively unimportant."

It is in these cities that the central place functions show their greatest strength. Significantly, all the cities of this group are located in the periphery. These are the cities most concerned with collecting, transferring, and distributing goods. It is not surprising that all five cities where transportation is the dominant function are in this group. Also in the group are the two cities where retail trade is dominant. Several cities act as political capitals as well as regional ones; included are Edmonton, Regina, Fredericton, and Halifax. The first three maintain functional profiles typical of regional capitals despite the government function. Halifax, however, because of the presence of a large military establishment in addition to other government activities, has a high rate of specialization. This is the only atypical specialization index in the group.

An additional four cities can be isolated on the basis of population size and relatively high values for both wholesale trade and manufacturing. They are the "major metropolitan centres." The positions of these cities in Figure 5 symbolizes the two distinct groupings of Canadian cities: periphery *vs.* heartland functional types. Winnipeg and Vancouver, located in the periphery are much more involved, relatively, with wholesale trade (also transportation) than Toronto or Montreal, situated in the heartland. On the other hand, the latter two cities emphasize manufacturing to a greater extent than their counterparts in the periphery. The implication is clear; a familiar thesis is again stated: the friction of distance requires urban centres in the periphery to "consume" greater amounts of "economic energy" in achieving their functional objectives than is required by the heartland cities. In keeping with the position of the heartland, its metropolitan centres are the largest cities in the nation and their influence infiltrates all segments of the national economy. The influence of the two periphery metropolitan cities, in contrast, is restricted to western Canada. The northern and eastern peripheries are essentially appendages of the heartland—as is the western periphery, but to a lower degree—and they do not have any cities that rank as national metropolises. They do have several cities that could be described correctly as "regional metropolises"; these have been included with the "regional capitals" in this grouping scheme.

The remaining twenty cities are "mid-way," in terms of specialization and importance of wholesale trade and manufacturing, among the specialized manufacturing centres, the regional capitals where manufacturing is relatively unimportant, and the special cities. In this group are found some of the best examples of multi-functional cities. It is perhaps the most heterogeneous group of all because there is no outstanding trait common to it. In the groups previously described all cities share one distinctive characteristic, be it: (1) a very high degree of specialization, (2) a high degree

of manufacturing importance, or (3) a high rate of wholesale trade importance combined with low ratings for manufacturing and specialization. The lack of any real "distinctiveness" in terms of specialization, wholesale trade or manufacturing means that many must be differentiated on the basis of other functional characteristics if detailed analysis is required. In general terms, the larger centres are regional capitals with a moderate to heavy emphasis on manufacturing, and the smaller cities, while often serving as regional capitals, do not have very significant wholesale trade functions. They are frequently involved with other types of activity such as government service and transportation. This group has been called "regional capitals: manufacturing relatively important." The title is not entirely satisfactory because the group is heterogeneous and the name obviously does not apply to all its members.

Six of the twenty centres in the group are periphery cities. They are all important regional capitals but also have significant manufacturing functions which are based on either local resources and/or advantages accruing from transportation factors. For example, the existence of local coking coal is basic to Sydney's iron and steel complex, local clay deposits and natural gas reservoirs provide the principal materials for Medicine Hat's clay products industry, and regional forest resources feed the large pulp and paper operations in Edmundston. Fort William-Port Arthur and Truro represent cases where transportation factors are of prime importance as underpinnings of the manufacturing function. Local resources are relatively unimportant in the two cities as factors in manufacturing location; the advantages accruing to break-in-bulk points and points of "centrality", respectively, provide the basis for their manufacturing. The existence of flour mills and oil refineries in Fort William-Port Arthur, for example, is directly related to the break-in-bulk feature. These periphery cities are only slightly more specialized than most of their counterparts which serve as regional capitals but where manufacturing is relatively unimportant. Sydney, however, is much more specialized than the others because of its heavy emphasis on iron and steel. In this respect it resembles closely the "specialized manufacturing centres."

Some functional diversity is exhibited by the heartland cities in this group. For example, Trenton, Barrie, and Pembroke are closely associated with military camps; St. Thomas is an important railway centre; Kingston is perhaps the closest approximation in Canada to an "institutional" centre, having important educational, military, religious, and penal facilities; Quebec City is a political capital; and Orillia is the site of a large mental hospital. Because of this diversity it is difficult to formulate general statements on these cities. Of note, however, is the fact that only two of the fourteen heartland cities in this group are members of the city clusters. Most of them are outside the clusters and are not typified by high specialization indexes as are centres of the manufacturing nodes. Even the two cities within the manufacturing cores are highly diversified in comparison to other member cities. Joliette is the least specialized of the centres in the two clusters and only two other member cities besides Joliette are more diversified than Sherbrooke. In essence, most of these heartland cities are basically regional capitals exhibiting functional profiles not very dissimilar from those of their counterparts in the periphery. Their rates of specialization, for example, are closer to those of the periphery service centres than to those of cities within the manufacturing regions. As stated in the preceding section, the propensity for obtaining special functions and moderately high rates of manufacturing activity is greater for the heartland regional capitals than for those of the periphery. This greater opportunity of obtaining additional city-forming functions enjoyed by the heartland regional capitals has tended to produce more complex functional structures because the additional functions are superimposed on the "service-centre type" of functional profile.

CONCLUSION

Although the city groupings developed do not allow an exhaustive analysis of city functional structure to be made, they do provide an overview of urban character in Canada. The distribution patterns studied illustrate the close relationship existing between the functional profiles of cities and the character of the economic regions in which the cities are located. They show that a fundamental difference exists between the functional profiles of the heartland and periphery cities, thus reflecting the major elements of Canadian economic geography.

The heartland, enjoying excellent locational relationships for most manufacturing processes—the key urban function—is the site of urban concentration as well as manufacturing concentration.

The region contained 52 per cent of Canada's population in 1951, yet it occupies only 2.5 per cent of the nations land area; forty-five of the eighty cities studied are in the heartland. Whereas great concentration of economic activity, financial power, and population exist in the heartland, the periphery is characterized by huge sparsely settled areas, giving it almost vassal status in its relationship with the heartland. The periphery, because of its involvement with the friction of distance, must devote much more its "economic energy" to overcoming this friction. In the heartland the friction of distance is comparatively of little consequence. These fundamental differences in situational characteristics are reflected by the functional profiles of the cities in the two regions.

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Appendix

Dominant and Distinctive Functions, and Specialization Indexes for Canadian Cities of 10,000 and More Population, 1951

WESTERN PERIPHERY

City	Specialization Index	Dominant Function	Distinctive Functions CLASS I : II : III
Lethbridge* *1.25 is the special index value for Lethbridge; extraction was omitted in its construction. The city's regular specialization index value is 11.69.	1.25	Retail Trade	Retail Trade Construction Wholesale Trade Finance, etc. Recreation Personal Service Extraction Public Utilities Transportation Business Service
Prince Albert	1.40	Manufacturing II	Recreation Community Service Construction Transportation Wholesale Trade Retail Trade Finance, etc. Government Service Business Service Personal Service

City	Specialization Index	Dominant Function	Distinctive Functions CLASS I : II : III
Brandon	1.41	Transportation	Transportation Wholesale Trade Finance, etc. Community Service Recreation Public Utilities Retail Trade Government Service Business Service Personal Service
Penticton	1.44	Transportation	Recreation Personal Service Construction Transportation Wholesale Trade Retail Trade Finance, etc. Business Service
Saskatoon	1.51	Manufacturing II	Wholesale Trade Finance, etc. Community Service Transportation Retail Trade Government Service Recreation Business Service Personal Service
Moose Jaw	1.56	Transportation	Transportation Recreation Public Utilities Construction Wholesale Trade Retail Trade Finance, etc. Community Service Personal Service
Calgary* *1.77 is the special index value for Calgary; extraction has been omitted in its construction. The city's regular specialization index value is 17.21.	1.77	Manufacturing II	Wholesale Trade Finance, etc. Recreation Public Utilities Construction Government Service Business Service Personal Service
Edmonton* *1.80 is the special index value for Edmonton; extraction has been omitted in its construction. The city's regular specialization index value is 14.96.	1.80	Manufacturing II	Construction Wholesale Trade Transportation Finance, etc. Government Service Business Service
Medicine Hat	1.97	Manufacturing II	Recreation Transportation Construction Retail Trade Finance, etc. Government Service Personal Service
Winnipeg	2.00	Manufacturing II	Wholesale Trade Finance etc. Transportation Recreation

Western Periphery

City	Specialization Index	Dominant Function	Distinctive Functions CLASS I : II : III
Fort William-Port Arthur	2.08	Manufacturing II	Transportation Public Utilities Construction Wholesale Trade Recreation
Regina	2.09	Government Service	Wholesale Trade Finance, etc. Government Service Public Utilities Transportation Retail Trade Community Service Business Service Personal Service
Vancouver	2.40	Manufacturing II	Wholesale Trade Finance, etc. Transportation Business Service
Victoria	4.01	Government Service	Government Service Finance, etc. Community Service Recreation
Trail	6.86	Manufacturing I	Manufacturing Recreation Business Service
Lethbridge	11.69		
Edmonton	14.96	*See* pp. 96, 97	
Calgary	17.21		

Northern Periphery

City	Specialization Index	Dominant Function	Distinctive Functions CLASS I : II : III
Chicoutimi	1.72	Manufacturing II	Community Service Construction Retail Trade Public Utilities Wholesale Trade Business Service Personal Service
North Bay	2.35	Transportation	Transportation Public Utilities Construction Wholesale Trade Retail Trade Finance, etc. Community Service Personal Service
Jonquière	4.40	Manufacturing I	Manufacturing Construction Retail Trade Personal Service
Sault Ste. Marie	4.70	Manufacturing I	Manufacturing Transportation Recreation

NORTHERN PERIPHERY

City	Specialization Index	Dominant Function	Distinctive Functions CLASS I : II : III
Arvida	8.96	Manufacturing I	Manufacturing Community Service
Rouyn	612.92	Extraction	Extraction Recreation Personal Service Construction Wholesale Trade Business Service
Sudbury	918.63	Extraction	Extraction Construction Recreation Personal Service
Timmins	1400.66	Extraction	Extraction Public Utilities Retail Trade Recreation

EASTERN PERIPHERY

City	Specialization Index	Dominant Function	Distinctive Functions CLASS I : II : III
Charlottetown	1.16	Retail Trade	Retail Trade Recreation Personal Service Wholesale Trade Finance, etc. Community Services Public Utilities Construction Transportation Government Service Business Service
Rimouski	1.36	Community Service	Community Service Construction Personal Service Public Utilities Business Service Transportation Wholesale Trade Retail Trade Finance, etc.
Moncton	1.55	Transportation	Transportation Retail Trade Wholesale Trade Finance, etc. Community Service Government Service Business Service Personal Service
Saint John	1.67	Manufacturing II	Transportation Wholesale Trade Recreation Finance, etc. Community Service Government Service Personal Service

EASTERN PERIPHERY

City	Specialization Index	Dominant Function	Distinctive Functions CLASS I : II : III
St. John's	1.75	Manufacturing II	Wholesale Trade Government Service Transportation Retail Trade Community Service Personal Service
Truro	1.77	Manufacturing II	Personal Service Transportation Retail Trade Wholesale Trade Finance, etc. Community Service Recreation Business Service
Fredericton	1.86	Government Service	Public Utilities Wholesale Trade Retail Trade Government Service Personal Service Construction Finance, etc. Community Service Recreation Business Service
Edmundston	2.35	Manufacturing II	Personal Service Transportation Community Service Construction Retail Trade
Sydney	5.21	Manufacturing I	Manufacturing Transportation Wholesale Trade Retail Trade Recreation Personal Service
Halifax	5.46	Government Service	Government Service Public Utilities Construction Transportation Wholesale Trade Finance, etc.
Glace Bay	1697.89	Extraction	Extraction
New Waterford	1952.46	Extraction	Extraction Retail Trade Recreation

HEARTLAND

City	Specialization Index	Dominant Function	Distinctive Functions CLASS I : II : III
Barrie	1.87	Manufacturing II	Public Utilities Retail Trade Finance, etc. Government Service Construction Transportation Recreation Business Service Personal Service

HEARTLAND

City	Specialization Index	Dominant Function	Distinctive Functions CLASS I : II : III
Belleville	2.04	Manufacturing II	Recreation Transportation Retail Trade Public Utilities Finance, etc. Government Service Business Service Personal Service
Quebec	2.11	Manufacturing II	Construction Wholesale Trade Finance, etc. Community Service Government Service
St. Thomas	2.14	Manufacturing II	Transportation Retail Trade Public Utilities Community Service Recreation Business Service Personal Service
Kingston	2.17	Manufacturing II	Community Service Government Service Retail Trade Finance, etc. Recreation Business Service
London	2.17	Manufacturing II	Finance, etc. Public Utilities Construction Wholesale Trade Community Service Government Service
Chatham	2.26	Manufacturing II	Public Utilities Retail Trade Recreation Construction Transportation Wholesale Trade Finance, etc. Community Service Business Service Personal Service
Brockville	2.71	Manufacturing II	Community Service Manufacturing Transportation Retail Trade Finance, etc. Recreation Business Service Personal Service
Owen Sound	2.73	Manufacturing II	Wholesale Trade Retail Trade Manufacturing Public Utilities Transportation Finance, etc. Recreation Business Service

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HEARTLAND

City	Specialization Index	Dominant Function	Distinctive Functions CLASS I : II : III
Orillia	2.74	Manufacturing II	Retail Trade Community Service Recreation Manufacturing Public Utilities Construction Finance, etc. Business Service Personal Service
Joliette	2.88	Manufacturing I	Community Service Manufacturing Public Utilities Construction Retail Trade Business Service Personal Service
Pembroke	3.41	Manufacturing II	Business Service Retail Trade Government Service Public Utilities Construction Community Service Recreation Personal Service
Toronto	3.51	Manufacturing I	Finance, etc. Public Utilities Wholesale Trade Business Service
Trois Rivières	3.52	Manufacturing I	Manufacturing Public Utilities Construction Community Service
Sherbrooke	3.61	Manufacturing I	Manufacturing Construction Wholesale Trade Community Service
Niagara Falls	3.62	Manufacturing I	Public Utilities Personal Service Manufacturing Recreation Business Service
Trenton	3.63	Manufacturing II	Government Service Construction Transportation Retail Trade Recreation Personal Service
Stratford	3.87	Manufacturing I	Manufacturing Public Utilities Transportation Retail Trade Finance, etc.
Sarnia	3.90	Manufacturing I	Construction Business Service Manufacturing Public Utilities Transportation

HEARTLAND

City	Specialization Index	Dominant Function	Distinctive Functions CLASS I : II : III
Montreal	3.92	Manufacturing I	Finance, etc. Wholesale Trade
St. Hyacinthe	3.96	Manufacturing I	Community Service Manufacturing Construction
Woodstock	4.14	Manufacturing I	Manufacturing Public Utilities Retail Trade Community Service
Cornwall	4.16	Manufacturing I	Manufacturing Retail Trade Recreation Personal Service
Guelph	4.22	Manufacturing I	Manufacturing Community Service
Shawinigan	4.53	Manufacturing I	Public Utilities Construction Manufacturing
St. Catharines	4.56	Manufacturing I	Manufacturing Construction Business Service
Kitchener-Waterloo	5.36	Manufacturing I	Finance, etc. Manufacturing
Windsor	5.41	Manufacturing I	Manufacturing
Peterborough	5.42	Manufacturing I	Manufacturing Finance, etc.
St. Jean	5.55	Manufacturing I	Government Service Manufacturing
St. Jérôme	5.56	Manufacturing I	Manufacturing Construction
Victoriaville	5.59	Manufacturing I	Manufacturing Public Utilities Construction Wholesale Trade
Brantford	5.67	Manufacturing I	Manufacturing Business Service
Hamilton	5.88	Manufacturing I	Manufacturing
Sorel*	6.05	Manufacturing I	Manufacturing
Drummondville	6.24	Manufacturing I	Manufacturing Personal Service
Granby	6.28	Manufacturing I	Manufacturing Construction Personal Service
Grand'Mère	6.34	Manufacturing I	Manufacturing Public Utilities Construction

*6.05 is the special index value for Sorel; extraction was omitted in the construction. The city's regular specialization index value is 10.93.

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HEARTLAND

City	Specialization Index	Dominant Function	Distinctive Functions CLASS I : II : III
Valleyfield	6.39	Manufacturing I	Public Utilities Manufacturing Construction
Welland	6.54	Manufacturing I	Manufacturing Business Service
Galt	7.14	Manufacturing I	Manufacturing
Oshawa	7.50	Manufacturing I	Manufacturing
Magog	7.56	Manufacturing I	Manufacturing
Ottawa	7.84	Government Service	Government Service Finance, etc. Recreation
Thetford Mines	1139.76	Extraction	Extraction Public Utilities Retail Trade

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GAS-DOMED MOUNDS IN PERMAFROST, KENDALL ISLAND, N.W.T.

J. Ross Mackay

ABSTRACT

Four gas-domed mounds were discovered on Kendall Island, Mackenzie River Delta area, N.W.T., in the summer of 1963. A physical description of the mounds is given, and it is postulated that the gas was probably methane, mixed with variable amounts of other gases, and generated by the anaerobic decay of plant material.

The possible thermal history of the development of the gas-domed mounds is discussed. Dating of the mounds utilizing combined evidence of tritium age of ice crystals, corresponding favourable sequence of climatic events, vegetation type, and small tundra polygon fissures all indicate an age prior to 1950. The most favoured date is 1945.

RÉSUMÉ

Quatre tertres soulevés par les gaz ont été découverts dans l'île Kendall, dans le delta du fleuve Mackenzie (T. du N.-O.) pendant l'été de 1963. L'auteur donne une description physique et suppose que le gaz est probablement du méthane, mélangé à des proportions variables d'autres gaz, et produit par la décomposition anaérobie des végétaux.

Il examine la possibilité que des forces thermiques soient à l'origine de ces tertres. On a déterminé leur âge en se fondant sur diverses preuves comme la détermination par le tritium de l'âge des cristaux de glace, la succession correspondante de phénomènes climatiques, les types de végétation, et les petites fissures polygonales du sol de la toundra. Tout indique que les tertres sont antérieurs à 1950, c'est-à-dire vers 1945.

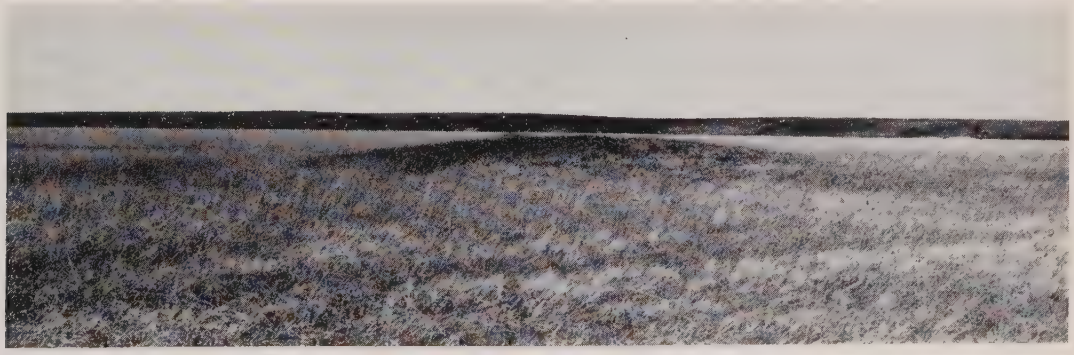

FIGURE 1. Mound A showing the alluvial flat and higher land of Kendall Island in the background.

Four gas-filled mounds were discovered on an alluvial flat at Kendall Island (69°29′N, 135°15′W) in the summer of 1963. When each of the mounds was bored, the drill rods penetrated into a cavity from which gas escaped. Upon ignition, the gas from the largest mound burned for 25 minutes, thus raising the suggestion that methane under pressure was present. The three smaller mounds collapsed within a day after release of the gas pressure. The largest mound (Figure 1) apparently collapsed in the fall of 1963 when floodwaters inundated the alluvial flats and entered the mound cavity by way of an excavation made into the mound. When seen again in the summer of 1964, a lake five to six metres across occupied the site of the centre of the mound.

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The mounds were on an alluvial flat about 1500 metres long and 750 metres wide partly infilling a bay. The flat, which is about 75 cm above mean sea level, is low enough to become inundated at times of strong westerly storms. The flats, for example, were submerged twice in July 1963, by fresh silty floodwaters from the Mackenzie River. Shallow lakes dot the flats, and interlake areas are sodden most of the summer. The moist tundra vegetation is composed largely of sedges and grasses without tussocks or bush willow, as on the adjacent higher land. A few tundra polygon fissures, 10 to 20 cm deep, trend randomly across the flats. Of the four mounds, only the largest was visible from a distance of 50 metres; the three smaller mounds were such minor swells that they attracted attention only after the largest mound was found to be filled with gas. Despite a careful search of the rest of the flat, and tens of square kilometres of similar areas, only one other possible gas-domed mound was seen, but it was not drilled. Clearly, the formation of the mounds required a very special set of conditions, otherwise more would have been present. A search of the literature has failed to locate any references to similar gas mounds in other permafrost areas, but it would be surprising if they did not occur. Certainly, air is known to escape from the apexes of some ice mounds (e.g. pingos), but in them the principal doming force has been the pressure of water.

DESCRIPTION OF THE MOUNDS

The largest mound, designated A, was 10 metres in diameter and reached a height of 75 to 80 cm above the adjacent flat (Figure 2). The vegetation was composed mainly of sedges with a few low willow, 10 to 15 cm high and more than 10 years old. The soil at the top was distinctly drier than that at the base.

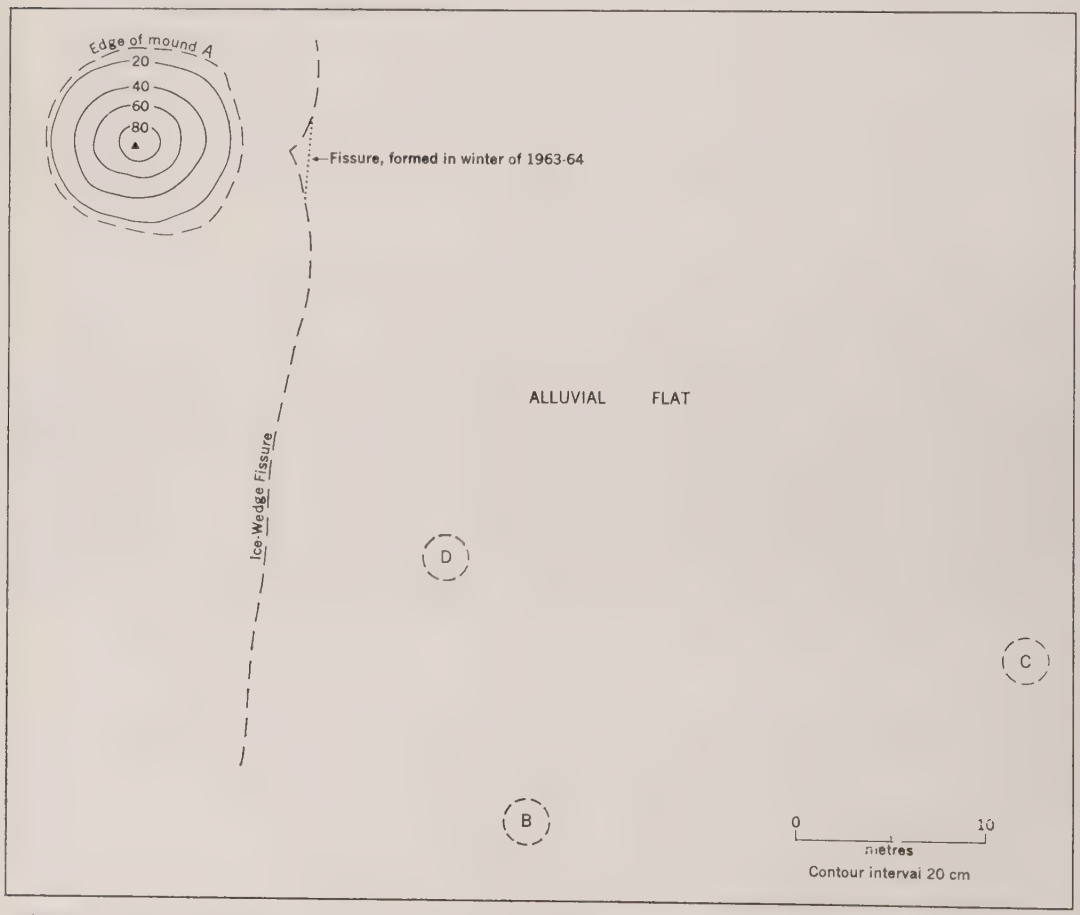

FIGURE 2. Map of the mounds. Mound A is shown with a 20-cm contour interval, the datum being slightly below the alluvial flat. The location of the drill hole is shown with a solid triangle.

When mound A was first examined, it was considered to be an incipient pingo similar to those that have grown as high as 10 metres on other alluvial flats of the Mackenzie Delta (Mackay, 1963, p. 88-94). As the mound seemed just the right size to excavate, it was decided to outline the shape of the ice core by drilling before actually digging into it. After the cutting bit had reached a depth of 135 cm the drill rods dropped about one metre, and gas hissed out from the vent. A match was struck to see if it would ignite. In a split second a "gas well" was spurting flames several feet into the air. The drill rods were pulled, and then an attempt was made to smother the flame with clods of moist earth but to no avail; in about twenty-five minutes the gas burned itself out. The discovery of gas in mound A suggested that three other nearby low mounds might also be gas blisters, hence they were drilled in turn. Gas issued from each of the drill holes, but the flow ceased before the drill rods were fully extracted—in less than 10 seconds. A trench was dug to gain an entrance into the cavity of mound A and the cavern was found to be a replica of the surface expression of the mound, but lined on its ceiling with beautiful ice crystals, like icy stalactites (Figure 3).

The 135 cm-overburden and the cavern ice crystals are depicted in Figure 4. The grain size limits are: sand 0.05 mm; silt 0.05 to 0.005 mm; and clay 0.005 mm. The peat of horizon (b) in Figure 4 was composed of local vegetation indicative of sedge and grass meadows with nearby willow thickets (analysis by J. Terasmae, Geological Survey of Canada). Horizons (c) and (d) were supersaturated with ice, having much more ice (water) than the soil could hold in the thawed state. The ice was clearly visible to the unaided eye. From horizon (e) to (g), the ice content decreased, until soil of horizon (g) became only slightly moist when thawed. Horizon (h) had plate-like and needle-like ice crystals. Horizon (i) had snow-white ice plates one cm or more in diameter. Horizon (j) had pendant hollow prismatic columns; the sides of the hexagonal columns averaged 2 cm wide, with an extreme of 4 cm; a few columns lacked one side; pendant angles ranged from vertical to 45°; columns were straight, zig-zag, or grew perpendicular from older columns (Figure 3).

The shapes of the ice crystals may be used to estimate the temperature range under which they grew. Under supersaturation conditions, thin hexagonal plates form at 0° to −3°C; needles at −3° to −5°C; and hollow prismatic columns at −5° to −8°C (aufm Kampe et al., 1951, p. 173; Mason, 1962, p. 69). Thus, the ice crystals of horizon (h) suggest a crystallization range of 0° to −5°C; horizon (i) a range of 0° to −3°C; and horizon (j) a range of −5° to −8°C. The period

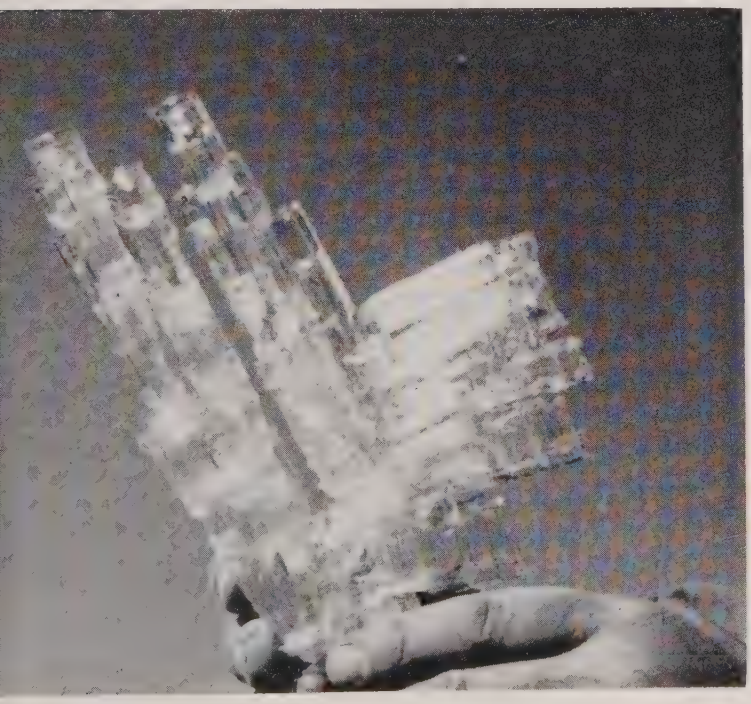

FIGURE 3

Prismatic ice crystals from the roof of the cavity of mound A. The long crystals hung vertically down.

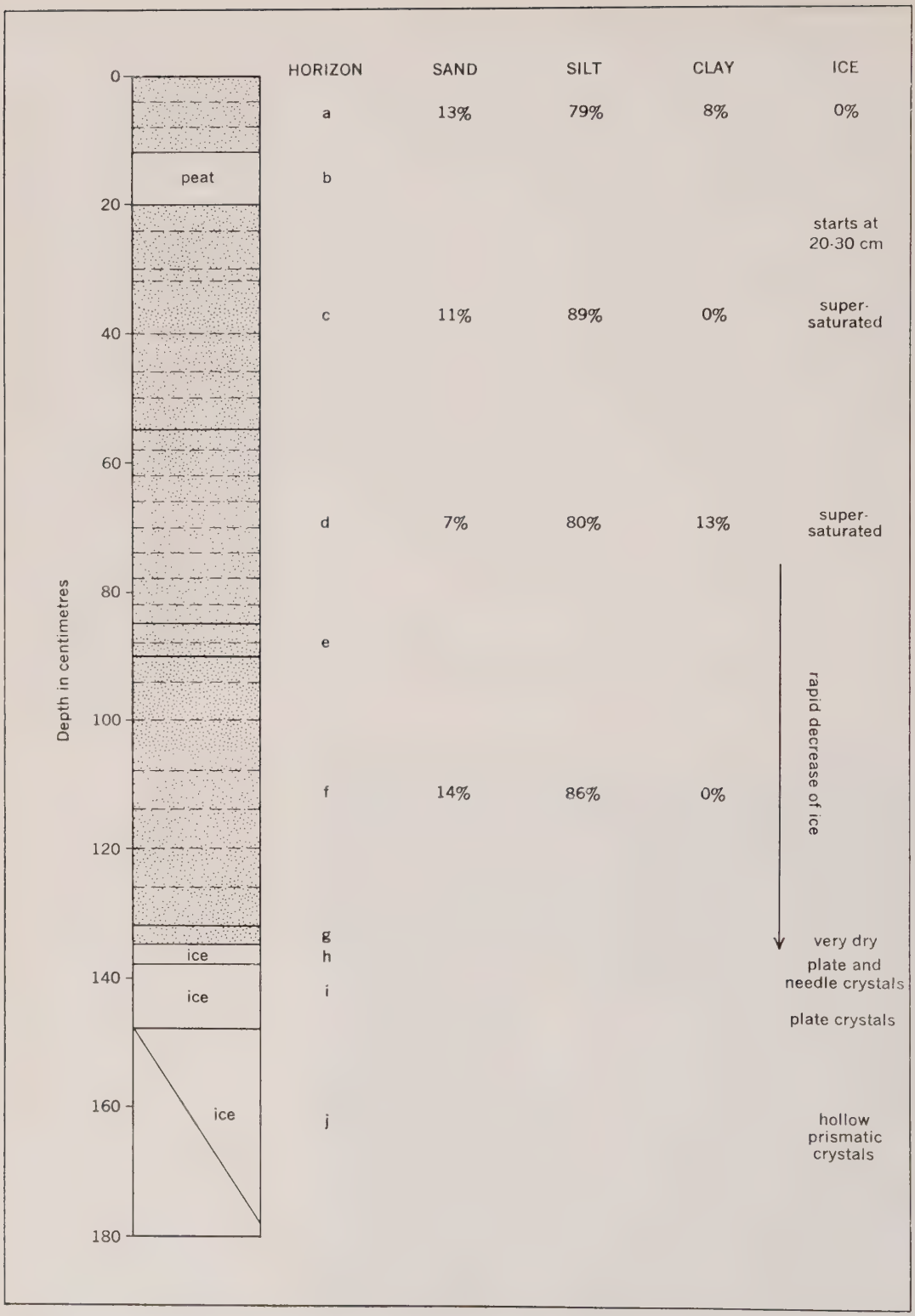

FIGURE 4. Cross-section through the overburden of the centre of mound A. The ice crystals of Figure 3 came from horizon j.

of crystallization was one of generally decreasing temperature, although horizon (i) suggests a slight temperature fluctuation.

A heap of ice and soil, fallen from the cavity roof, had accumulated to a height of 30 cm beneath the centre of the mound. Other detached fragments from the cavern roof, up to 50 cm across, littered the floor, which was covered with a powder-dry layer, 1 to 4 cm thick, of sandy silt (about 15% sand, 79% silt, 6% clay), like sifted flour. No ice crystals had grown on the floor. Beneath the dusty soil, there was a hard icy sandy to silty clay.

Data on mounds B, C, and D for July 7, 1963, are given below:

Mounds

	B	C	D
Diameter (metres)	3	2	2
Height above flats (cm)	20	15	15
Overburden thickness (cm)	51	58	51
Cavity height (cm)	8	8	11
Depth of thaw (cm)	29	27	29
Peat bed, depth (cm)	14-29+	15-27+	14-29+

ORIGIN OF THE GAS

The gas that issued from the mounds was probably methane with variable amounts of other gases. Methane is generated by the anaerobic decay of plant material such as has accumulated in lake bottoms, marshes and swamps. Bubbles of inflammable gas frequently rise from the bottoms of lakes and channels in the Mackenzie Delta area. In winter, when an ice cover forms over water bodies, the released gas is trapped and may dome thin ice. This is well known to trappers who frequently punch holes through the ice and ignite the gas which may then burn for a few seconds to half an hour. Ruttner (1963, p. 198), writing of European conditions states:

> "This demonstration becomes especially impressive when one taps the huge bubbles often formed under the ice of a lake by the rising of this gas, and then ignites the outflowing methane. At times a jet of flame 1 metre high is produced in this way."

Gas also accumulates at the feeding station or "pushup" of muskrats in the Mackenzie Delta lakes.

> "These do not close readily, as bubbles of gas rising to the surface seem to keep them open. If a hole does freeze, it forms a dome-shaped space filled with gas and the ice above it remains thin. Pushups are usually built at such locations. The gas apparently comes from the decomposition of organic matter . . . The generally slow rate of decomposition in northern lakes produces a slow continuous release of gas, and in this way pushups are perpetuated year after year in the same location."

(Stevens, 1953, p. 21). Gas pressure can not only dome up thin ice sheets, but also lake bottoms to form islands. In Germany, an island 60 metres long and 30 metres wide suddenly emerged from water about 3 metres deep on October 23, 1910 (Hutchison, 1957, p. 175). Other similar cases of buckling have been reported, with the pressure attributed to gas. Thus, gas pressures of considerable magnitude may originate from the trapping of methane.

The rate at which methane and the associated gases can be produced under Kendall Island conditions must be speculative, at best. Some species of bacteria, which are quite abundant, can produce methane at low temperatures, such as 5°C (Ruttner, 1963, p. 198). A rate for low temperatures is given by Allgeier, Peterson, Juday, and Birge (1932) who found that 1 litre of bottom mud from Lake Mendota, Wisconsin, when covered with water in the absence of air at 7°C evolved about 55 cc of gas in 200 days. At the end of the period of fermentation, the amount remaining in solution was about one-third of that evolved. Therefore, about 75 cc were produced per litre during 200 days incubation at 7°C. Thus, a layer of mud 10 cm thick evolved about 100 cc per cm^2 of surface area per year, excluding that remaining in solution. Thicker layers would evolve proportionately more gas. If the gas could not escape because of a covering of frozen soil, gas pressure would be built up beneath it.

THERMAL HISTORY

The seasonal depth of thaw in the alluvial flats fluctuates from year to year, depending upon climatic and hydrologic conditions. Warm or cold seasons, early or late snowstorms, and infrequent or frequent flooding will vary the depth of thaw. In the summer of 1963, the depth of thaw in mid-July was about 30 cm.

The depth (z) of thaw for a uniform soil is approximately

$$z = \frac{2t\,Tk}{72n} \qquad (1)$$

where t is time; T the ground surface temperature; k the conductivity of the soil; and n the porosity of the soil (Terzaghi, 1952, p. 41). If it is assumed that the depth of thaw in mid-July, 1963, was measured under mean conditions of a normal season, then the estimated depth of thaw for the summer of 1963 was 42 cm. The depth could not be checked in the field, but judging from measurements of past field seasons, it seems to be a reasonable estimate. In order for thaw to penetrate down

to 51 cm, which is equal to the thinnest overburden of any of the four mounds, the application of equation (1) suggests that: the latter half of the 1963 summer would require a mean temperature 2.6 times the first half, if the duration of the season remained unchanged; or the period of thaw would require at least a month's extension, if the mean temperature remained unchanged; alternatively both the mean temperature and length of thaw should be increased appreciably.

The inference is, therefore, that the depth of thaw could penetrate through the 51 cm overburden of mounds B and D, only during exceptionally deep thawing. Extreme thawing conditions would be needed for a 58-cm penetration through the overburden of mound C, and it would be impossible, under present climatic conditions, for seasonal thaw to reach a depth of 135 cm in mound A.

Deep thawing does occur beneath some of the lakes on the flats. The extent of unfrozen ground beneath a lake is primarily a function of the mean water temperature and distance from shore. For example, on July 13, 1963, a lake was probed seven metres from shore where it was two metres deep. The temperature was 10°C at the bottom of the lake and 3°C one metre below the bottom thus giving a gradient that would place the frost table at a considerable depth. On July 10, 1963, probings of shallower lakes and channels showed 50 to 70 cm of unfrozen bottom sediments under 15 to 20 cm of water. Thus, by the end of summer, the depth of thaw under such shallow lakes may reach 70 to 100 cm and lakes 30 to 50 cm deep might sustain an unfrozen column 150 cm deep in summer.

The 135-cm overburden in mound A included considerable ice. The ice content of the thawed part was not measured, but horizons (c) and (d) contained abundant visible ice lenses. The lenses show that extensive segregation had occurred and the heave could easily account for 20 or 30 cm of the total succession. Thus, the thickness of the original unfrozen overburden might have been only 115 or 105 cm, perhaps less. Then, if the full 135-cm overburden were collapsed into the gas cavity and so returned to its original position, a 35-cm deep depression would mark the site on the flats. In an unfrozen state, however, the 135 cm might easily settle to a thickness of 105 cm and the depression would then be 65 cm deep. Thus, it is possible that the mound surface before uplift was at the bottom of a lake 30, 50, or perhaps 65 cm deep.

The mounds were apparently domed by gas trapped beneath a frozen impermeable overburden. Their origin thus resembles that of a laccolith, hydrolaccolith, or some types of pingos. Gas (predominantly methane) cannot evolve in, or escape through, frozen sediments, and therefore at least three factors seem necessary for mound formation: (1) the evolution of gas over a "long time" at low temperatures in unfrozen sediments; (2) the spread, from the surface downwards, of a frozen layer to trap the gas; and (3) the arching of the frozen layer by gas pressure to form the mound.

For the generation of methane and its accumulation in the mound, soils to a depth of at least the 135-cm overburden thickness were initially unfrozen. Consider, therefore, a 135-cm column of soil beneath a lake 35 cm deep and estimate temperatures required to thaw or freeze the soil. The conductivity of the soil is unknown but some representative values in cgs units are: icy silt, .006; frozen organic silty clay, .003; ice peat, .0045 (Lachenbruch, 1959, p. 10); and ice, .0053. As the soil is silty, the ice content is high, a peat layer is present, and organic matter is distributed throughout the soil, therefore the conductivity may range from about .003 to .006.

In similar soils at Aklavik the moisture content in the upper three metres ranged from 60 to more than 150 per cent on a weight basis (Pihlainen and Johnston, 1954, p. 12). An estimate of the porosity (n) for Aklavik soils, gives a range of about .4 to .7+ with a preference for higher values. If the "over-all" porosity for the mound site, which would include the 135 cm of overburden and 35 cm of lake water is considered, the mean porosity would range from about .52 to .76.

The thickness (z) of soil that can be frozen in time (t) can be approximated by an expression identical to equation (1) except for sign, viz:

$$z = \frac{-2tTk}{72n} \qquad (2)$$

Equation (2) is based on Stefan's simple solution for thin ice, modified for soils. It gives results nearly identical to those derived from Neumann's more precise solution (Ingersoll, Zobel, and Ingersoll, 1954, pp. 190-198), and therefore the simpler method is used here.

In applying the formula to determine the temperatures required for both freezing and thawing of the mound-site overburden in a single winter

or summer season, let us assume the following conditions:

z = 170 cm
t_1 = freezing period, October to May, 243 days
t_2 = thawing period, June to September, 122 days
k = .003 (icy peat), and .006 (icy silt) cgs
n = .52 and .76

This gives the following required temperatures:

	Freezing, t_1 = 243 days		Thawing, t_2 = 122 days	
	k = .003	k = .006	k = .003	k = .006
n = .52	T = − 8.6°C	T = −4.3°C	T = 17.1°C	T = 8.5°C
n = .76	T = −12.6°C	T = −6.3°C	T = 25.0°C	T = 12.5°C

It is well known that mean annual ground temperatures in arctic areas tend to be several degrees higher than mean annual air temperatures. Of particular importance is the insulating effect of the winter snow, which may cover the ground from November to May. For instance, at Aklavik during periods of continuous cold, the temperature at a depth of 30 cm in snow was 10°C higher than the snow surface temperature (Williams, 1957, p. 4). If precipitation is converted into snow, using the 1/10 ratio, the mean monthly snowfall in centimetres at Aklavik is: November, 19; December, 13; January, 14; February, 11; March, 10; and April, 12. The mean six-month total is 79 cm. Thus, in a year with heavy snowfall, it does not seem unreasonable that an average of at least 30 cm of snow might cover the ground for the six-month period of November to April. This crude estimate cannot be verified, but enquiries from natives lends substantiation to the estimate. The theoretical insulating effect of a six-month snow cover on mean annual ground temperature has been investigated by Lachenbruch (1959, pp. 28-30). If his approach is employed, by using a depth of 30 cm of fresh snow over lake ice in the computations, the mean annual lake temperature might be raised 4°C over an otherwise uninsulated air-solid interface. This, in effect, implies a mean winter temperature about 8°C higher than the uninsulated air-solid interface.

As there is no climatological station at Kendall Island, data from Aklavik, 170 km to the south, is used in the following discussion. The climatic norm is for the 1931 to 1960 period. Where the Aklavik record is incomplete, the missing data have been interpolated from Fort McPherson and Fort Good Hope records. Kendall Island temperatures are doubtless slightly lower than those of Aklavik. The mean air temperature at Aklavik for the freezing period of October to May is −18.3°C and that for the thawing period of June to September is 9.2°C, giving an annual mean of −9.1°C. At Inuvik, 65 km east of Aklavik, the mean annual air temperature is possibly 5°C lower than that of the ground (Brown, 1960). It is apparent, therefore that during exceptionally warm winters, preceded by a heavy autumn snowfall, ground temperatures could easily be high enough to preclude lake-bottom freezing to a depth of 170 cm.

To summarize, if the 135-cm overburden were returned to its original position in the gas cavity and thawed, the base would lie at 170 cm below the flats and a depression would be formed, at least 35 cm and perhaps 65 cm deep, and occupied by a lake. Under mean temperature conditions, the summer depth of thaw could reach to 170 cm if the melting of ground ice in the overburden produced a deeper lake, e.g. of 50 cm. However, given a heavy and early snowfall, freezing might not reach 170 cm in a lake 35 cm deep, and it would be even more unlikely in one 50 cm deep. Consequently, the base of the overburden was at a critical depth where a heavy autumn insulating snowfall, accompanied by high winter temperatures, would result in the winter preservation of an unfrozen—i.e. methane generating—layer sandwiched between the top of permafrost and frozen lake-bottom sediments.

The lower surface of a downward penetrating freezing plane beneath a basin-shaped lake would tend to be dome-shaped (Mackay, 1962, p. 51) primarily because freezing would be delayed in the deeper lake centre where the unfrozen sediments would be the thickest. Therefore, if gas were being generated in unfrozen sediments, the gas would be expelled from the sides towards the centre, if the permeability permitted, when a closed system developed. As the area of fermentation was encroached upon by infreezing, gas might migrate towards the lake centre to create large pressures. Here, it is believed, the increasing pressure was relieved by updoming where the frozen ground was thinnest, viz: near the lake centre.

The preceding analysis suggests that gas pressures could develop the first winter, possibly with a slight amount of doming. The effects of doming would be several. There would be shoaling over the dome so that the seasonal depth of thaw would be lessened; as the ground warmed up in summer to the freezing point, a compressive stress due to thermal expansion might accentuate the dome; and a partial thawing of the overburden would reduce the bending strength of the overburden.

Once a surface mound were formed, the seasonal depth of thaw would be decreased, because the mean annual temperature would be lower than in the submerged state. After the freezing plane crossed the bottom of the cave, whether from a downward or upward advance, the supply of methane would be cut off.

The small sizes of mounds B, C, and D may be attributed to an earlier cutoff of their gas supply, probably by freezing during the first winter.

AGE

An ice sample from the hollow prismatic ice crystals was melted in a sample bottle carefully rinsed with tritium-free water and dated by the tritium method. (The dating was by Dr. R. M. Brown, Atomic Energy of Canada). The age corresponded to a precipitation date of 1945 with 7.0 TU. The standard deviation is estimated at ± 5 years. Although the tritium concentration could be established by exchange of the ice with atmospheric moisture in recent years, it seems unlikely, because any exchange would have allowed the methane to escape. Estimates of the age of the mound can also be made in two other ways. If the mound was domed up from a lake bottom, then it took place prior to 1950, because some willows on the mound date to that period. Another line of evidence is given by a tundra polygon fissure tangential to the mound, but with a small cusp pointing to the mound centre. As fissures tend to propagate at right angles to the greatest tension (Lachenbruch, 1962, pp. 44-45), the cusp indicates stress relief concurrent with, or subsequent to, mound growth. During the winter of 1963-64, the winter crack bypassed the cusp (Figure 2), doubtless because the mound had collapsed. As the fissure is only several inches deep, and is a minor feature, it can hardly be more than a few decades old, if the yearly ice vein growth is of the order of several millimetres, which seems reasonable from field observations.

An examination of the climatic records shows that the most favourable period for mound growth, since the beginning of climatic observations at Aklavik in the late 1920's, was from 1942 to 1947, on the assumption that Aklavik records reflect trends at Kendall Island.

A summary of the 1942-1950 Aklavik climatic data is given below. The mean winter temperature is for October to May, inclusive; the mean summer temperature is for June to September, inclusive. The standard period of comparison is the climatic norm of 1931 to 1960. The estimate of the shift in the mean winter temperature has been based upon the theory given in Lachenbruch (1959, pp. 28-30). The amount of snow lying on the ground from October to March is assumed arbitrarily to be 60 per cent of the October-December total. This does not seem unreasonable, because some snow usually falls in September, and the effect of a snow cover may last until May. The shift of temperature is based upon average data for packed drifted snow; it would be greater if the snow were fresh. In other words, conservative data are used.

1942 Summer: temperature 1°C above normal, being in the upper quarter for the 1931-1960 period.

1942-43 Winter: temperature 2°C above normal, being in the upper tenth; second highest snowfall October-December (8.4 cm water equivalent) in 30 years; snowfall warming effect 8°C.

1943 Summer: temperature 1.5°C above normal, being in the upper tenth.

1943-44 Winter: temperature 3°C above normal and warmest winter in 30 years; rain and snow in September 46 per cent above average; heaviest snowfall in October-December (10.7 cm water equivalent) in 30 years; snowfall effect 8.8°C.

1944 Summer: nearly normal temperature.

1944-45 Winter: nearly normal temperature and snowfall; snowfall effect 7°C.

1945 Summer: nearly normal temperature.

1945-46 Winter: temperature 1°C below normal; very light October-December snowfall (1.4 cm water equivalent) which was only 24 per cent of the average; snowfall effect 2.4°C.

1946 Summer: normal temperature.

1946-47 Winter: temperature .4°C below normal; exceptionally light October-December snowfall (0.5 cm water equivalent), only 9 per cent of average; snowfall effect 1.2°C.

1947 Summer: temperature 1.5°C below normal and in lowest tenth.

1947-48 Winter: temperature 1.5°C above normal; slightly above normal snowfall; snowfall effect about 7°C.

1948 Summer: temperature normal.

1948-49 Winter: 1°C colder than normal; snowfall nearly normal; snowfall effect about 7°C.

1949 Summer: temperature nearly normal.

1949-50 Winter: temperature 2.8°C above normal, in upper tenth; below normal snowfall; snowfall effect 6°C.

Figure 5 shows an attempt to estimate, in °C, how much warmer or colder the summer and winter air-lake interface was, compared to normal, for the 1942-1950 period. The mean winter warming shift due to snowfall is taken as 7°C.

The mean annual temperature at a depth of 14 metres for three years at Inuvik has been given as −3.4°C with a mean annual air temperature of −8.9°C (Brown, 1960, p. 170). The mean annual air temperature at Kendall Island is unlikely to differ by more than several degrees from that at Inuvik, although it is probably lower. Mean ground temperatures of about −6° or −7°C, seem reasonable (Mackay, 1963, p. 77). It follows then that average. In the cold 1945-46 winter, the thickness of unfrozen ground was greatly reduced. In the normal summer of 1946, thawing was insufficient to melt all the ground frozen in the preceding abnormally cold winter. Thus, a frozen "seal" persisted at depth to prevent the escape of methane. In the next succeeding cold winter of 1946-47, the unfrozen layer was again reduced in thickness and likewise thawing in the cold summer of 1947 was minimized. If this hypothesis is correct, then the impermeable seal which commenced to form on the lake bottom in October-November, 1945, would have prevented the escape of methane from then onwards. Methane would have been evolved until the unfrozen layer was frozen, probably not before the spring of 1947. Thus, methane might have evolved in a closed system for at least a year and

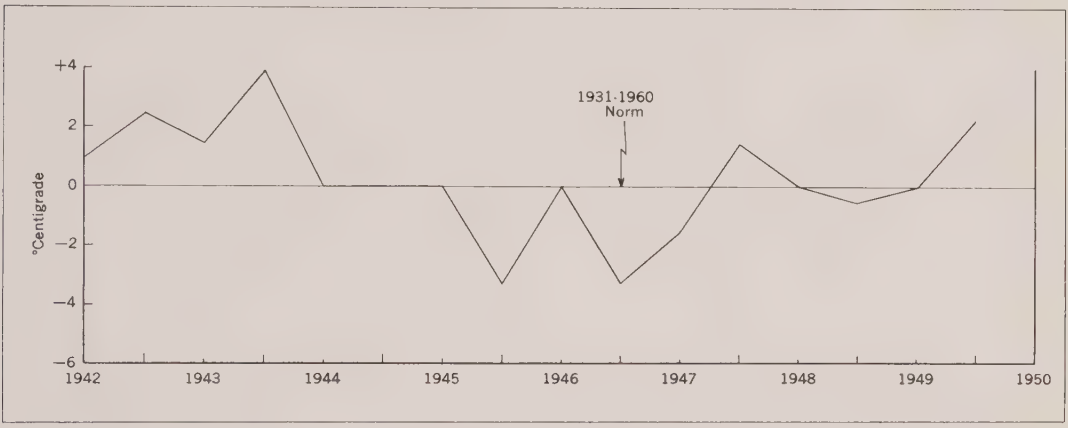

FIGURE 5. Suggested direction and magnitude of "summer" and "winter" temperature departures from the corresponding climatic norms when snowfall is taken into account.

mean lake bottom temperatures would be higher than −6° or −7°C, depending upon lake depth. Thus a slight rise in summer and winter temperatures would be very effective in inducing thaw in lake-bottom sediments where the temperatures were previously within several degrees of zero.

On the assumption that an unfrozen zone normally persisted below a shallow lake down to a depth approximating the bottom of the cavity of mound A, Figure 6 suggests diagrammatically how the mound might have grown: The summer depth of thaw was greater than average in the warm summers of 1942 and 1943; the winter depth of freeze was considerably less than average during the mild winters of 1942-43 and 1943-44. Thus, during the normal winter of 1944-45, the thickness of unfrozen ground remained much deeper than a half. As pressure increased, the yielding overburden was raised above the lake, and the mound was exposed to low air temperatures and froze solidly to the bottom, thus preventing further growth.

The cavity had a floor area of about 80 square metres; mean height of about 40 cm; and volume of 33 cubic metres. If about 1.00 cc of methane evolved per cm^2 of surface per year, per 10-cm-thick layer, then an unfrozen layer 50 cm thick would generate enough methane to "cover" the cavity floor about 5 cm thick in one year, at atmospheric pressure. Although the estimated generation period for the methane in mound A is of the order of several years, it is doubtful if all the methane could have been generated solely within the area embraced by the cavity. If how-

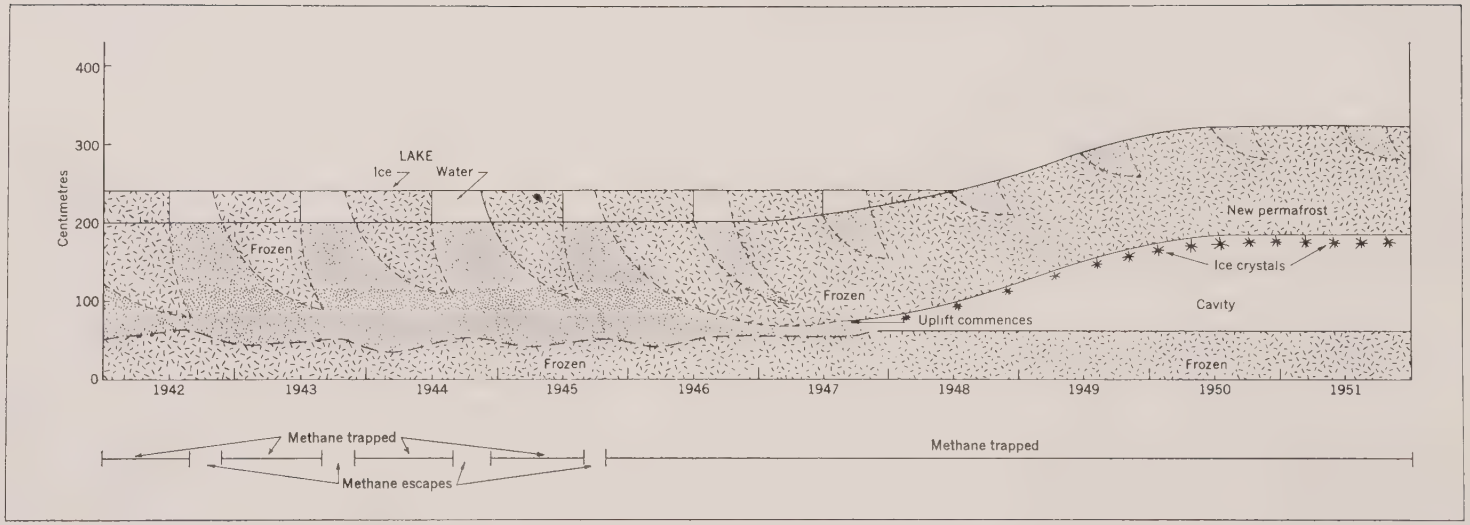

FIGURE 6. Schematic diagram suggesting how a vertical column of soil at the site of the centre of mound A might have responded to temperature changes during the 1942-1951 period.

ever, the source area extended over a radius of 10 or 15 metres, instead of 5 metres, pressures considerably exceeding one atmosphere might have been generated in a short period. An estimate has been made of the heat released in the evolution of methane within the cavity. Although it would serve to prolong the period of methane production, the time involved seems to be negligible.

The preceding sequence of climatic events, which has been suggested as being most favourable to mound formation, was determined prior to, and therefore independent of, the subsequent tritium age determination of 1945 ± 5 years. The combined evidence of the tritium age, corresponding favourable sequence of climatic events, vegetation type, and the small tundra polygon fissure, all indicate an age prior to 1950. The most favoured date is 1945.

CONCLUSIONS

The methane-domed mounds of the distal portion of the Mackenzie Delta are unique features requiring a special set of circumstances for their growth. Although methane is produced in innumerable lakes and channels, the gas normally escapes freely in the summer, or may be trapped beneath ice for all or part of a single winter. The mounds under discussion are believed to have formed when a permafrost seal spread across a lake bottom over unfrozen lake muds evolving methane. The initiation of the seal required a critical combination of lake depth, summer thaw, and winter freeze.

Quite probably some other low mounds that would normally be identified as young pingos are, in fact, gas-domed mounds. However, the overburden thicknesses to a depth of 5 metres are known for more than twenty such mounds in which no gas, but ice, occurs to that depth. Therefore, if gas is present, the cavity must be at a considerable depth in relation to mound height. There is also the possibility that methane, evolved at a depth of some tens (?) of metres in the distal part of the Delta islands may escape upwards to dome mounds like laccoliths. Such a possibility should not be dismissed, because perennial "gas springs," which have been active for decades, do occur.

ACKNOWLEDGMENTS

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BREAK-UP ON THE MACKENZIE RIVER AND ITS DELTA, 1964

D. K. MacKay

ABSTRACT

Aerial and ground observations made during the 1964 break-up season on the Mackenzie River and in the Delta area are reported and discussed.

Dates of first ice movement opposite settlements along the main river channel were later than normal. One factor delaying the break-up was the unusual thickness of the ice cover in the vicinity of Fort Simpson. Dates of complete ice clearance were also late, reflecting in part the destruction of the massive ice jams at The Ramparts and Fort Norman.

Break-up in the Mackenzie Delta was a placid event with no threat of flood developing at any of the Delta settlements. The peak water level at Inuvik was reached within twelve hours of that in 1954 the only previous record available.

RÉSUMÉ

Les observations aériennes et terrestres effectuées au cours de la débâcle en 1964 du fleuve Mackenzie et de son delta font l'objet de la présente étude.

La date des premiers mouvements de la glace en face des habitations qui longent le chenal principal a été plus tardive que dans le passé. La forte épaisseur de la glace au voisinage de Fort Simpson a contribué au retard de la débâcle. La disparition complète des glaces s'est produite tardivement, en raison des amoncellements de glace aux Remparts et à Fort-Norman.

Dans le delta du Mackenzie, la débâcle s'est déroulée normalement, sans qu'aucun des hameaux du delta soit menacé d'inondation. Le niveau maximal de l'eau à Inuvik, a été atteint une douzaine d'heures plus tôt qu'en 1954, seule année ou on a procédé à des observations.

INTRODUCTION

The Canadian Ice Distribution Survey of the Geographical Branch has been collecting and analyzing data on lake and river ice conditions for more than a decade. One major river for which continuous records are being kept is the Mackenzie.

The Mackenzie River and its tributaries drain an area of 696,000 square miles, second only in North America to the area drained by the Mississippi River system (Thomas, 1957). It is, moreover, the longest river in Canada and one of the ten longest in the world (Mackay, 1961). From an economic viewpoint, the river is of great importance to settlements both along its banks and on the western arctic coast.

During its ice-free season, the Mackenzie River (Figure 1) is navigable over the 1071 miles from its head in Great Slave Lake to its mouth at the Beaufort Sea. Following spring break-up, commodities are barged along this waterway, resupplying the settlements and providing the equipment and materials required for oil exploration, construction, and other purposes. Break-up is, consequently, an eagerly awaited event and one that can be critical to the welfare of the inhabitants of the District of Mackenzie.

Dates of break-up and freeze-up of Canadian rivers are normally recorded by non-professional observers. For example, Mackenzie River break-up is recorded by missionaries, settlers, Royal Canadian Mounted Police, airline crews, and others. Their observations are very useful, but there is often doubt that the event reported as break-up at one location is characteristically the same as that reported for another location. Differences can be expected because the criteria used to define break-up depend on the interests of the observer. It is possible that an observer may regard any stage of ice movement, from the incipient shifting of the ice cover through to complete ice clearance, as river break-up. Break-up is, however, generally defined as either the date of the first

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FIGURE 1
Location map

movement of ice downstream, or as the date of complete ice clearance.

To interpret this year's observations correctly and to develop an over-all appreciation of the Mackenzie break-up process, a number of flights over the river and its delta were undertaken by the writer in the latter part of May, 1964.

THE BREAK-UP PROCESS

Normally, the first phase of break-up on the Mackenzie River is generated by radiational melting of snow along its banks and on the surrounding valley slopes. Meltwater trickles down the banks and pools along the sides of the channel. As the melting process continues, narrow leads of open water develop along the edge of the shorefast ice. These leads are enlarged where flow from tributaries enters the main channel. Similar strips of open water occur around islands and alluvial bars in the river.

The intermediate phase of break-up begins as moderating temperature and precipitation cause marked increases in the run-off. As the water level rises in the channel the decaying ice cover fractures and splits into numerous large rafts and pans. Flow from tributary streams may open leads across the full width of the river. Initial downstream ice movement tends to be intermittent and slow as some sections of the ice cover remain shorefast or anchored in shallow reaches of the river.

As the intermediate phase continues, abrasion and melting reduce the ice cover to a mass of smaller pans and ice wreckage. Downstream movement is accelerated until jamming occurs at natural constrictions or sharp bends along the river's course. With the exception of these ice jams, the main channel is now open.

The final phase of ice clearance is marked by the destruction of the ice jams. Characteristically, the pressure of impounded water behind the jams combines with the processes of abrasion, melting, and candling of ice to cause their disintegration. In the downstream surges that follow, ice wreckage is piled along the banks and the channel is swept clear of ice.

BREAK-UP IN 1964

1. Aerial Observations

May 9th—observations by Pacific Western Airlines aircrew showed the Mackenzie River and the

lower stretches of its major tributary, the Liard, to be completely covered by ice.

May 19th flight, Edmonton to Inuvik—the flight was carried out over ten-tenths cloud from Fort Smith past Fort Simpson. For the remainder of the flight, improved weather conditions allowed intermittent observation of river-ice conditions.

Glimpses through broken cloud revealed short stretches of the Mackenzie River to be open below Fort Simpson. From Mile 400 downstream narrow open water leads were present along both banks, around islands, and bars that emerge at the low-water stage. These leads extended for some distrance beyond the upstream and downstream ends of the bars and islands (Figure 2). At tributary junctions with the main stream, the shore leads were enlarged, the open areas extending on occasion into the mid-channel reaches.

With few exceptions, lakes on both sides of the Mackenzie were completely frozen over (Figure 3). Two exceptions noted were small lakes on the east flat, four miles south of Norman Wells; both were open along their shores.

May 23rd flight, Inuvik to Edmonton—lakes along the flight path between Inuvik and the Mackenzie River (Mile 820) showed first evidence of breaking up. Water was pooling around the lake perimeters and some openings were visible where major streams flow into the lakes.

The extent and appearance of the ice cover on the Mackenzie, from Mile 820 south to Norman Wells, had changed considerably from that seen on the previous flight. In the intervening four-day period, large open water pools had developed, particularly in the shallow reaches of the river. Some melting of snow on the main ice cover had caused a mottled pattern to develop on the previously uniform white surface.

At Norman Wells, fractures now extended across the full width of the remaining ice cover. Ice pans, cleaved from the main ice mass, were jamming the shore leads. By this date, the river had risen 6 feet above the winter-ice level (personal communication, R. Hill). The state of ice-cover decay suggested that any triggering mechanism would generate some ice movement.

All lakes in the Norman Wells area showed evidence of ice-cover disintegration. Some that appeared solidly ice-covered on the previous flight were three- to four-tenths open water, and the two small lakes, 4 miles south of Norman Wells, were nine-tenths open. The rate of ice-cover disintegration was extremely high for the four-day period between this flight and the previous one.

No observations were possible from Mile 560 to Fort Providence owing to the track of the aircraft and cloud cover. A view of the western end of Great Slave Lake revealed an area of open water, 3 miles by 7 miles in extent, off Big Island at Mile 0.

May 26th flight, Edmonton to Inuvik—on the flight north, the first remnants of lake ice were observed on the western side of Lake Claire, 100 miles south of Fort Smith. In the area between Fort Smith and Great Slave Lake, the centres of some lakes were still covered by ice.

Although the Hay and Slave rivers were ice-free, the movement of barges from shipping points (Hay River and Fort Smith) to the head of the Mackenzie did not appear feasible because of the ice remaining on Great Slave Lake. The visible part of the lake was ice-covered except for a thin strip of open water along its southern shore.

The river was again under ten-tenths cloud on the flight leg north to Norman Wells. At Norman Wells, the pattern and extent of Mackenzie ice-cover showed no appreciable change. North of the settlement, however, open stretches were more numerous and larger (four- to five-tenths open water) than previously observed.

On some meanders and curved sections of the Mackenzie, in areas where the ice cover was sufficiently shattered for some movement to take place, pans and ice wreckage tended to consolidate on the channel side next to the cut banks. Thus, open areas existed mainly off point bars and slip-off slopes. This was generally the case between Norman Wells and Mile 820. Beyond Mile 820, the Mackenzie was no longer visible from the aircraft.

May 28th flight, Inuvik to Yellowknife—in the area along the flight path, between Inuvik and the Mackenzie, open water leads now extended completely around the perimeters of lakes.

The river, from Mile 820 up to The Ramparts (Mile 680), was still approximately five- to six-tenths covered by ice. At the foot of The Ramparts, the ice was jammed. Above the head of the jam, little evidence of rafting or pressure ridging was seen, but consolidation of ice in the previously open areas had taken place back through the Sans Sault Rapids (Mile 632), as far upstream as Mile 600. Upstream from Mile 600, the river had partially inundated many of the lower islands. Some flooding of islands in the river was apparent up to the outlet of the Great Bear River (Mile 513).

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FIGURE 2

May 19, Mile 567. The intermediate stage of break-up; side channels are well developed and open-water areas extend around the islands.

FIGURE 3

May 19, north of Mile 820 of the Mackenzie River. Travaillant Lake, seen here, is still solidly covered by ice. This is typical of ice conditions on all lakes observed between Inuvik and the Mackenzie River.

FIGURE 4

June 11, Mile 665. Dirty Mackenzie River ice is piled on shore above The Ramparts, site of a major ice jam.

One of the famous landmarks of the Mackenzie River valley, Bear Rock, stands at the junction of the Great Bear and Mackenzie rivers. This was the site of a second major ice jam. Massive rafting of pans and compression of ice wreckage had resulted in the development of an immense ice structure that reached into the lower levels of the Fort Norman settled area (more than 30 feet above normal river level), and extended 15 miles upstream. The white under-surfaces and sides of overturned slabs contrasted with the grey-black upper surfaces of 'dirty' Mackenzie River ice (see Figure 4) to visibly stress the angular character of the jam's structure.

South of the ice jam, the river was clear to Mile 400, except for occasional patches of drifting ice. No further observations of Mackenzie ice conditions were possible on this flight.

2. Ground Observations

Recorded observations show that the break-up on the main channel was later than normal in 1964. The progress of break-up, as recorded at settlements and other locations along the main channel, was as follows:

Mackenzie River Break-up from Fort Providence (Mile 50) to Arctic Red River (Mile 897) inclusive

Location	Miles from Great Slave Lake	1964 Observations
Wrigley Harbour	03	May 16—open water in harbour
Fort Providence	50	May 15—river-ice broken and jammed; large open holes exist
Horn River	65	May 18—clear of ice
Mills Lake	70	May 18—beginning to break
Fort Simpson-Liard River	208	May 10—moved but did not push into the Mackenzie
		May 18—moved and stopped; continued on the 19th
Fort Simpson-Mackenzie River		May 17—ice moved below Liard and stopped; continued on the 18th
Martin River	217	May 20—ice went out
Wrigley	360	May 22—ice moved this date
Fort Norman	512	May 23—ice moved 500 yards and stopped at Bear Rock
		May 24—river 10 feet above winter ice level
		May 28—river still rising
		May 29—river holding, then breaking
		June 3 —jam broken wide open
		June 4 —river all clear
Norman Wells	564	May 24—ice shifted
		May 27—ice started moving
		June 1 —water-level dropping
		June 2 —river almost ice-free except for few ice pans
		June 3 —river clear of ice
The Ramparts	674 to 682	May 28—solidly jammed; pans breaking off and moving past Fort Good Hope
		June 1 —some ice wreckage passing through The Ramparts
		June 2 —main jam broke at 1130 hours
Fort Good Hope	683.5	May 24—ice moved for 4 hours
		May 25—ice moved for 2 hours
		May 26—ice moved for 3 hours
		May 27—3 miles of clear water
		May 30—ice moving steadily
		June 1 —river wide open south of The Ramparts almost to Norman Wells
		June 2 —river full of ice from The Ramparts jam
		June 3 —river clear; water still rising
		June 4 —scattered ice on river
		June 5 —river clear of ice
Arctic Red River	897	May 26—river rising but ice solid
		May 28—ice moved 200 yds. in mouth of the Arctic Red River
		May 30—Arctic Red River ice moving
		May 31—Mackenzie broke at 2300 hours; water running heavy with ice
		June 1 —heavy movement of ice
		June 6 —only scattering of ice left
		June 7 —river clear of ice

Dates of First Ice Movement, Mackenzie River

Location	1964 Date	Mean Date	Days later in 1964
Fort Providence	May 15	May 18.6	—3.0 days
Fort Simpson-Mackenzie River	May 17	May 11.5	5.5 days
Fort Simpson-Liard River	May 10	May 6.1	3.9 days
Fort Norman	May 23	May 14.2	8.8 days
Norman Wells	May 27	May 15.1	11.9 days
The Ramparts	June 2	May 22.9	10.1 days
Fort Good Hope	May 24	May 15.0	9 days
Arctic Red River (Settlement)-Mackenzie River	May 31	May 24.0	7.0 days
Arctic Red River (Settlement)-Arctic Red River	May 28	May 25.1	2.9 days

The lateness of break-up at all settlements other than Fort Providence may be illustrated by a comparison of the 1964 dates of first ice movement with adjusted mean dates for the 10-year period 1946-55 (*see* J. Ross Mackay, 1963).

The time of break-up depends on many interrelated hydro-meteorological and physical factors. For example, ice thickness, a major element affecting break-up, is dependent on winter temperatures, variability in the extent and depth of snow cover, changes in albedo, the amount of cloud cover, the effective radiation as influenced by the slope and aspect of the river's banks, river entrenchment and so on. The unusual ice thickness in the spring of 1964 on the Liard River (60 inches with 40 inches of clear blue ice) and the Mackenzie River (90 inches with 60 inches to 80 inches of clear blue ice), as measured near Fort Simpson, undoubtedly was of considerable importance in delaying the initial break-up and in slowing its progress downstream.

Break-up at settlements below Fort Simpson, as far downstream as Fort Good Hope, occurred 9 to 12 days later than established means. Further downstream, at Arctic Red River settlement, ice on the Mackenzie moved 7 days after the mean date. The apparent shift toward the mean for this location may be related to the break-up of the Arctic Red River; that is, Arctic Red River ice pushing into the Mackenzie channel may have created favourable conditions for the accelerated movement of Mackenzie River ice.

Dates on which the Fort Norman and Fort Good Hope stretches of the river were reported clear of ice were largely determined by the disintegration dates of the two major ice jams that occurred on the Mackenzie in 1964. The Ramparts jam, above Fort Good Hope, broke on June 2nd. The main mass of ice passed the settlement the same day with some of the ice remnants passing as late as June 4th. The river was declared free of ice on June 5th. Ice lining the banks in the area of the jam and below it was still much in evidence in the middle of June (Figure 4). The jam at Bear Rock began breaking on May 29th, broke wide open by June 3rd, and the channel was free of ice the following day. At one stage, ice was piled on the lower terrace within the settlement fringe, more than 30 feet above the river's surface. Ice standing along the bank at Fort Norman made access from the river difficult as late as June 8th and undoubtedly for some time thereafter.

BREAK-UP IN THE MACKENZIE DELTA

Compared with previous years, the 1964 break-up was a relatively placid one. None of the Delta's settlements were seriously threatened by flood.

A survey flight conducted on May 20th showed that Delta channel conditions were similar to those observed on the lower stretches of the main Mackenzie. Ice surfaces were extensively covered by snow with narrow bands of open water lying along channel banks (Figures 5 & 6). Delta lakes connected to channels were partially inundated and open around the edges; others not obviously connected showed little evidence of melting (Figure 7). At Inuvik the shore lead on the East Channel was so wide that an aircraft charter company was using a rowboat to reach the landing strip on the main ice cover.

A flight conducted on May 27th showed the occasional small tributary channel to be completely free of ice (Figure 10). A few lakes, presumed to be the shallower ones, were mainly open (Figure 14). Some flooding was evident in low areas adjacent to the Middle Channel, particularly in the vicinity of Horseshoe Bend (Mile 960). Roughly eight-tenths of the Aklavik Channel was covered by decaying ice. Open water areas of the Peel Channel appeared green with the exception of a stretch immediately below its head near Point Separation; there, turbid conditions resulted from the inflow of the Mackenzie waters.

FIGURE 5

May 20, Delta. An example of the first phase of Mackenzie Delta channel break-up.

FIGURE 6

May 20, Delta. The first phase of break-up at a channel branch, southwest of Inuvik.

FIGURE 7

May 20, Delta. Lakes connected to channels (centre of photo) show evidence of melting along their edges; those not connected (foreground) are still solidly covered by ice.

FIGURE 8

May 23, Delta. Inuvik and the East Channel; the main ice cover is in use as an airstrip.

FIGURE 9

May 27, Delta. Junction of the Middle and Kalinek Channels (looking north); note the open leads along the banks and the cleaving of pans from the main ice cover.

FIGURE 10

May 27, Delta. A small ice-free tributary channel south of Aklavik.

In 1963 ice jams blocking the Middle Channel at Horseshoe Bend and the head of the East Channel raised the water level in the west side of the Delta, threatening Aklavik. In 1964 no jams of any magnitude were reported although the Delta was under almost continuous surveillance by various interested groups. In fact, there was little evidence of ice rafting even at channel sites where ice movement was stopped for some time.

Observations recorded for the Delta in 1964 follow:

Mackenzie Delta Break-up, 1964

Location	Observations
Point Separation, Mile 913	May 27—channels open along edges; ice appears rotten; head of East Channel open
	May 30—a fair amount of water with ice
	June 1 —ice broken, candled but not moving
	June 6 —ice remnants moving out
Fort McPherson, Peel River	May 27—open upstream, close to McPherson; water rising but still very low; sandbar off settlement not yet covered
	May 28—ice broke at 2300 hours; moved 500 yards and stopped; ice badly broken
	May 30—Peel running high and muddy; most of small channels in area open
	May 31—ice still moving
	June 1 —Peel Channel jammed at Middle Channel; ice candled
	June 5 —river clear of ice
Lang Trading Post, Junction of Phillips and Peel Channels	June 1 —Peel Channel covered with large ice pans as far as Aklavik; clear upstream
Horseshoe Bend, Middle Channel	May 12—ice thickness averages 55 in.; range of 49 in. to 60 in. (5 holes); all clear blue ice
	May 30—opening and breaking slowly
	June 1 —open stretches down to Oniak Channel; large pans upriver
	June 6 —flowing heavily with ice; large areas of open water
Aklavik, Peel Channel	May 29—water rising; small cracks in ice surface and edges open
	May 30—ice too soft for aircraft
	June 3 —ice breaking at bend
	June 5 —ice packed at Aklavik but clear for some distance downstream
	June 6 —ice moving steadily and water level dropping
	June 7 —river clear of ice
Inuvik, East Channel	May 13—ice thickness 42 in. (1 hole)
	May 29—ice shifted and moved 20 ft.
	May 30—ice moved 200 ft.
	May 31—ice moved for 35 minutes
	June 1 —ice broken to airport lake; some ice to Gull River but clear above to Middle Channel
	June 2 —almost clear; some small pans
	June 3 —running heavy with Mackenzie (dirty) ice at 2200 hours
	June 6 —ice remnants still running
	June 7 —river clear of ice
Reindeer Station, East Channel	May 30—ice solid; aircraft landed on ice evening of May 29
	June 10—all channels clear to outer Delta islands
	July 7 —lakes on outer Delta islands still with ice centres

The single observation of ice conditions for the Peel Channel opposite Lang Trading Post does not specify the date of first ice movement, but it does suggest that it occurred about June 1st. Break-up at this location can be estimated from break-up dates at Fort McPherson (May 28) and Arctic Red River (May 31, Mackenzie River ice moved) with regression equations computed by J. R. Mackay (1963). Using only Fort McPherson (X_1) and counting days to break-up from April 30, break-up at Lang Trading Post (X_0) becomes:

$$X_0 = 15.4 + .62X_1 = 32.8 = \text{June } 1.8.$$

Adding the second independent variable, Arctic Red River (X_2), the equation for break-up at Lang Trading Post becomes:

$$X_0 = 10 + .31X_1 + .42X_2 = 31.7 = \text{June } 0.7.$$

The computed range, June 0.7 to 1.8, agrees with

FIGURE 11

May 27, Delta. Marked linear pattern in decaying ice cover of Middle Channel at the East Channel branch; the latter is free of ice for a distance of 10 miles downstream. Note diamond shaped navigation markers.

FIGURE 12

May 27, Delta. Large ice rafts in the East Channel, south of Gull River.

FIGURE 13

May 27, Delta. East Channel between Kalinek branch and Gull River. Generally, as in this case, there is more open water on the inside of the meander curve.

FIGURE 14

May 27, Delta. Variability in the progress of break-up of Delta lakes; the shallow lake in the foreground is directly connected to a channel.

the time of first ice movement suggested by the recorded observation.

Reindeer Station (X_0) break-up may be similarly computed (J. R. Mackay, 1963) using Fort Good Hope (X_1) as the independent variable as follows:

$$X_0 = 24 + .61X_1 = 38.6 = \text{June } 7.6.$$

WATER LEVELS AT INUVIK, EAST CHANNEL

The winter ice level at the Inuvik dock was used as a datum plane to determine water levels during the 1964 break-up season. In 1954, a similar set of observations was recorded by Brown (1957) at East Three, the present location of Inuvik, using the winter low-water level as a datum plane. These records are shown graphically in Figure 15. It should be noted that neither datum plane is related to a permanent bench mark and, thus, a comparison of heights is meaningless. Of interest, however, is the in-phase character of the maximum peaks; they differ only by twelve hours. Within a day of reaching these peaks, the East Channel was clear of ice.

The 1964 water levels (recorded by L. Adrian and R. Hill) are listed here so that further comparisons can be made as more records become available:

Water Levels at Inuvik Dock, 1964

Day	Hour	Water Level (Feet and Inches)	Day	Hour	Water Level (Feet and Inches)
May 23	0800	1: 9	May 31	0900	7: 4
				1220	7: 7
May 24	1100	2: 3		1820	8: 4
	1400	2: 7		2200	9: ½

Water Levels at Inuvik Dock, 1964 (continued)

Day	Hour	Water Level (Feet and Inches)	Day	Hour	Water Level (Feet and Inches)
May 25	0700	2: 8	June 1	0700	10: 9
	1220	2: 9		1200	11: 1
	1800	2: 11		1800	11: 6
	2300	3: 0		2340	12: 0
May 26	0700	3: 1½	June 2	0700	12: 6
	1230	3: 4		1220	13: 3
	1800	3: 6		1800	13: 3½
	2315	3: 8		2300	13: 3½
May 27	0700	3: 11	June 3	0700	13: 8
	1210	4: 1½		1205	13: 10
	1800	4: 4		1800	14: ½
	2300	4: 5½		2220	14: 1
May 28	0700	4: 8½	June 4	0700	14: 6
	1220	4: 10½		1205	14: 8
	1800	5: 1		1800	15: 0
	2300	5: 3		2220	15: 1
May 29	0700	5: 6	June 5	0800	15: 8
	1205	5: 8		1205	16: 0
	1800	5: 9½		1800	16: 2
	2300	5: 11		2300	16: 3
May 30	0700	6: 2	June 6	0700	16: 3½
	1220	6: 5		1205	16: 4
	1800	6: 8		1800	16: 5
	2300	6: 9½		2300	16: 5
			June 7	1205	16: 9
				1800	16: 9

Observations after June 7th are as follows: June 10th at 1600 hours, 14 ft 1 in.; June 11th at 1000 hours, 13 ft 4 in.; June 13th at 2000 hours, 11 ft 2 in.; June 14th at 1500 hours, 10 ft 7 in.; and at 2100 hours, 10 ft 5 in.; and June 15th at 1700 hours, 10 ft 0 in.

OPENING OF THE NAVIGATION SEASON

The main ice cover of the Mackenzie River normally breaks up before Great Slave Lake is open. Consequently, vessels wintering at Hay River

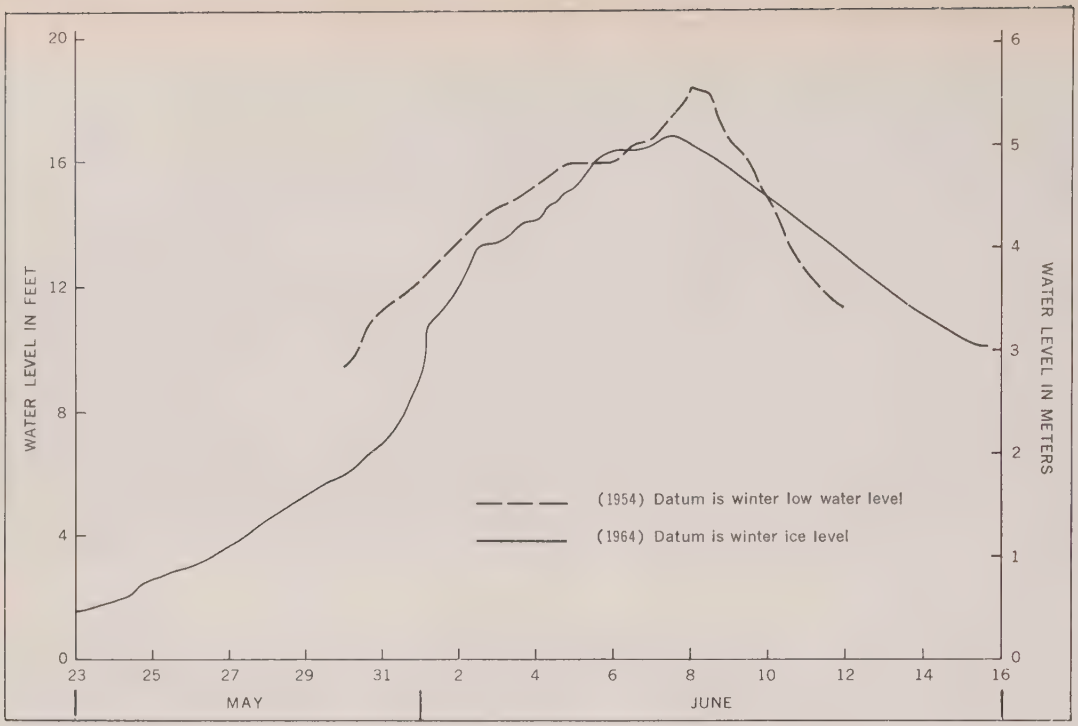

FIGURE 15. Water levels during the break-up season, East Channel at Inuvik. Data sources: 1954 (Brown, 1957), 1964 (Adrian, 1964)

and Fort Smith cannot reach the head of the Mackenzie when navigation initially becomes possible on the upper reaches of the river. In the spring of 1964, the first Northern Transportation Company vessel left Fort Smith on June 2nd and arrived at Great Slave Lake on June 3rd but was unable to penetrate the ice. The first crossing from Slave River to the head of the Mackenzie was completed on June 12th.

Another N.T.C. vessel left Hay River on June 5th and encountered ice to Wrigley Harbour (Mile 03). The voyage down-river was continued on June 7th, the navigation season being considered open from that date. In the Mackenzie Delta, however, some ice was encountered in the navigation channels until June 10th. The first N.T.C. sailing south from Inuvik occurred on June 9th (personal communication, W. S. Hall).

The writer journeyed down the Mackenzie, leaving Fort Providence (Mile 50) on June 1st. On that date, barges were loading at Fort Providence and vessels were navigating the stretch down to Fort Simpson and, possibly, beyond. The ferry service across the Mackenzie River near Fort Providence began operations on an unscheduled basis on May 29th.

ACKNOWLEDGMENTS

The writer is greatly indebted to L. Adrian, Civil Defence Co-ordinator at Inuvik, for his compilation of observations on Mackenzie break-up, and to R. Hill, Manager of the Inuvik Research Laboratory, for his personal observations and additions to the record. Grateful acknowledgment is made to Pacific Western Airlines, Northern Transportation Company, and individuals in settlements along the Mackenzie River for information supplied.

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THE CORRIES OF THE NORTHERN NAIN-OKAK SECTION OF LABRADOR

J. T. Andrews

ABSTRACT

The pattern of corries in the northern Nain-Okak section of Labrador is described and explained as being dependent on two variables, (a) the inclination of the last Saglek glacial limit and (b) the incidence of areas with sufficient relief. Thus the analysis shows that on the coast the corrie orientation is varied and the height of the corrie floor/backwall junction is about 300 m; westward the altitude of this junction increases and orientation becomes progressively restricted toward the northeast. An examination of the present climate suggests an anomalous relationship between the major precipitation-bearing air flows and corrie orientation. The lack of practical and theoretical work on these problems along the eastern Arctic seaboard is stressed.

RÉSUMÉ

Après avoir décrit l'orientation de cirques glaciaires de la partie nord de la région Nain-Okak (Labrador), l'auteur explique qu'elle dépend de deux facteurs variables, savoir, l'inclinaison que les glaciers de cirque avaient lors de la dernière glaciation, celle de Saglek, à son maximum, et le nombre des régions dont le relief était suffisamment élevé. Il s'ensuit que l'orientation des cirques du littoral varie et que l'altitude du lieu de rencontre des cirques et des murs de rimaye est d'environ 300 m. A mesure qu'on avance vers l'ouest, cette altitude augmente et les cirques sont de plus en plus orientés uniquement vers le nord-est. L'étude du climat actuel fait croire à l'existence d'un rapport anormal entre cette orientation et les grandes masses d'air en mouvement qui apportent de la pluie. L'auteur souligne qu'en ce qui concerne le littoral est des régions arctiques, on manque de travaux pratiques et théoriques relatifs à ces questions.

INTRODUCTION

Tanner (1944) and Flint (1943) considered that the expansion of corrie glaciers from the coastal "mountains" of Labrador led to the development of the main inland ice which eventually completely covered the coastal mountains. In this theory typical "armchair" corries must of necessity, therefore, have been formed in early and/or late-glacial time. Recent work by Ives (1957, 1958), Løken (1962) and Andrews (1963) suggests that this theory should be revised. Instead it has been proposed that the ultimate major glacial phase did not result in a complete ice cover. The upper limit of this, the Saglek glaciation, is marked by a series of massive lateral moraines and kame terraces that can be traced northward for about 360 kilometres. However, Ives and Løken concluded that during the penultimate, or Koroksoak glaciation the high Torngat summits were nunataks, although it appears that the Nain-Okak area was inundated by the continental ice sheet.

Within the northern Nain-Okak section (Wheeler, 1935) the upper limit of the Saglek phase lies between 468 m and 855 m depending upon location. The main mountain blocks contained active corrie glaciers, for the duration of this glaciation, which coalesced with the major valley glaciers flowing eastward and northward from the main inland ice. The boundary for continuous ice cover was primarily topographically controlled and lay along the junction of the *Valley* zone and *Inland Plateau* zone (Andrews, 1963). To the south the decrease in absolute elevation resulted in a complete ice cover at the maximum of the Saglek glaciation.

Thus, though mention has been made of the role of corries during the last glaciation there has been no attempt to rationalize their seemingly random orientation and arrangement. Despite the

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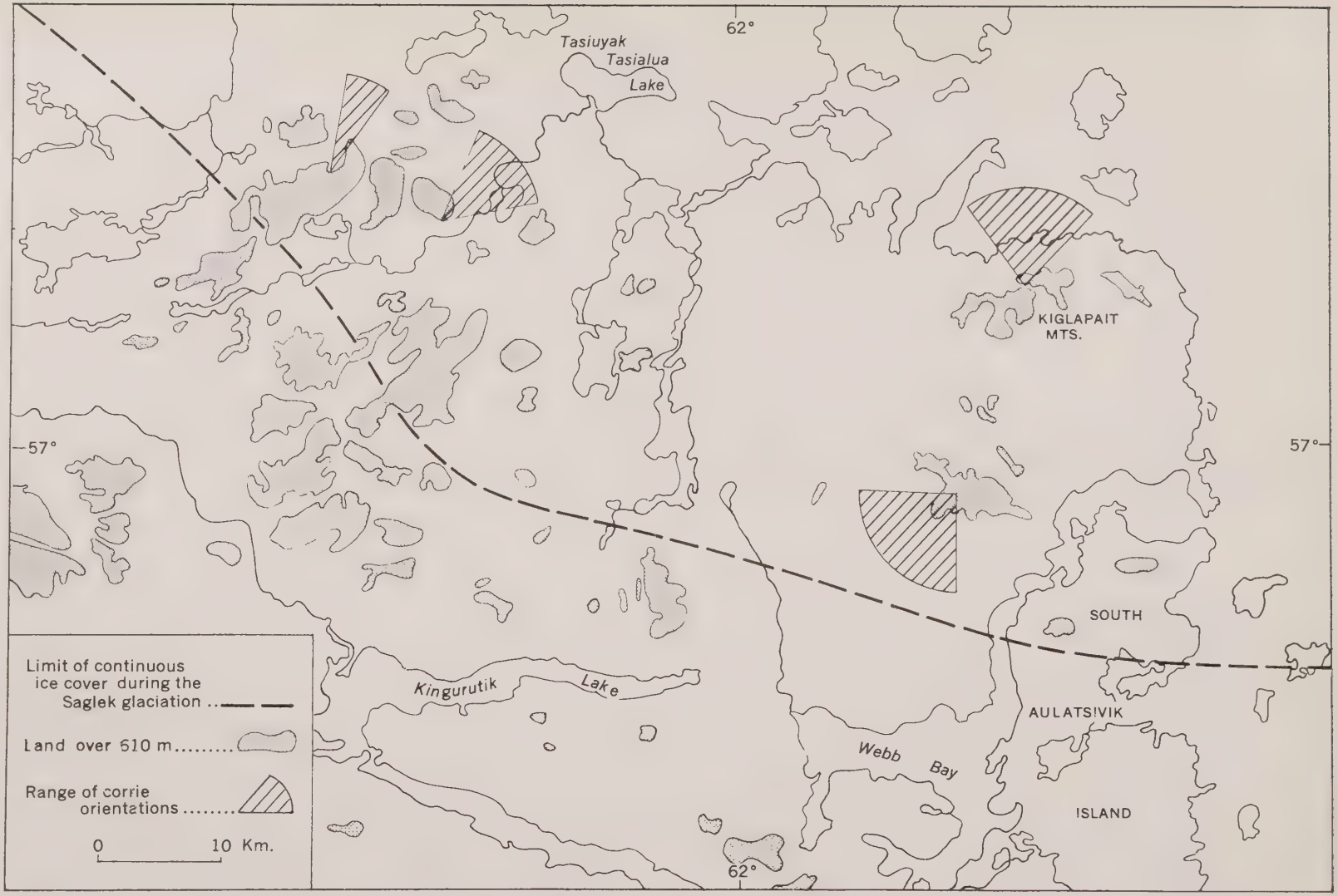

FIGURE 1. Location map, northern Nain-Okak area, Labrador coast.

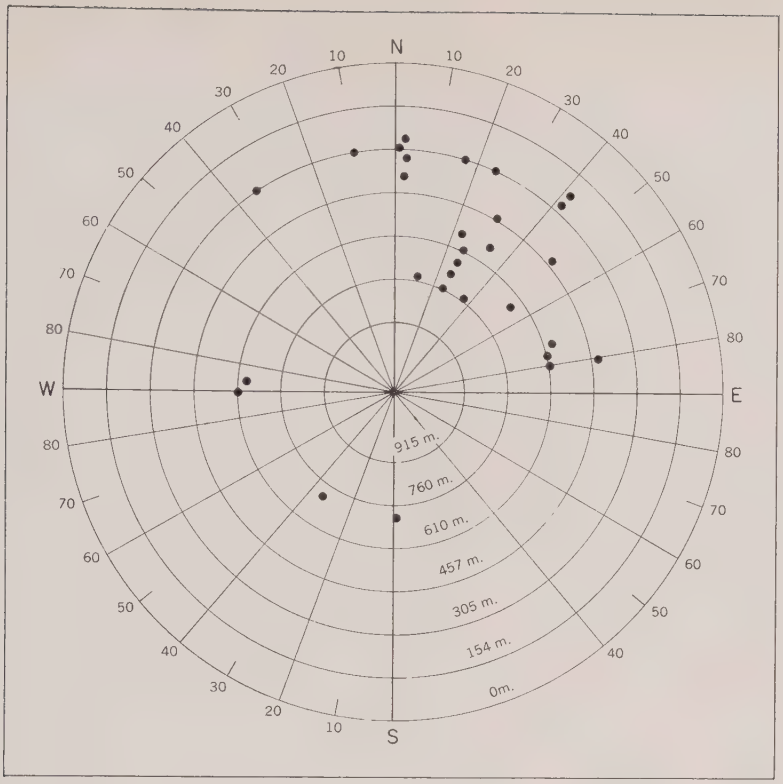

FIGURE 2

Orientation and height of the corrie floor/back-wall junction of the northern Nain-Okak corries.

limitations of available data, this paper presents such an examination in an attempt to provide useful information on the climatic conditions that were prevalent during the maximum of the Saglek glaciation.

No precise definition of a corrie is proposed, the study being limited to well defined features that are obviously in that category.

CLIMATE

Little climatological data are available for the coast. The following rough summary has been taken from Tanner (1944) and Barry (1959). The average annual temperature at Nain is −4.8°C with a June-September mean of 7°C. Winter precipitation is probably of the order of 30 to 40 mm water equivalent. Winds are predominately from the northwest; mean winter wind direction at Hopedale is from N82°W and in summer from N39°W. Barry (1959) has shown that 22 per cent of the air flow in summer can be classified as easterly; this leads to summer temperatures 2°C below those experienced with a westerly air flow. The air-flow patterns produce a tendency toward a continental climate even on the coast; this is clearly illustrated by a continentality index of 45 to 50 per cent (MacKay and Cook, 1963). However, as Barry (1959, p. 150) states: "The mountains of Labrador are unfortunately little known in terms of their climatology, but snowfall amounts at present seem light." He also points out that a predominant easterly flow would probably result in rain, except at high elevations along the east coast. West, modified west, and easterly flow are probably the most significant factors in the winter snowfall.

LOCATION AND PATTERN OF THE CORRIES

The broad physiographic breakdown of the Nain-Okak section proposed by Wheeler (1935) is essential to an understanding of the glacial history. The corries are located within the *Valley*, or *Bay and Island* zones where the relative relief is at a maximum and where the drainage of glaciers eastward from the continental ice sheet, through well defined valleys and troughs, resulted in an anastomosing system that did not inundate the higher mountains.

A study of air photographs covering the field area led to the identification of 29 corries, some containing one or more end moraines. No corries were noted west of 62°40′W or south of 56°50′N. The northern boundary was chosen as latitude 57°25′N. The broad pattern of corrie orientation can be seen on Figure 1. During the air photograph interpretation the orientation of the corries was measured, and the altitude of the corrie floor/backwall junction was determined by a study of the photographs and the available maps. The results are considered accurate to ±38 m. During the summer field season elevations were checked with aneroids and found to be within the stated accuracy.

This information has been plotted on a polar equidistant projection with the radial scale representing altitude and the circumferential scale azimuth (Seddon, 1957). A general clustering of corries orientated towards the northeast can be seen on Figure 1. In Figure 2 the corries have been subdivided into regional groupings, the north Kiglapait* group, south Kiglapait group, the central group and finally the western group of corries (Figure 3). Seventy-two per cent of the corries lie between north and east while 89 per cent are restricted to the northern half of the diagram. The altitudes of the floor/backwall junction vary widely; the lowest are at about 224 m and the highest at 760 m above sea level. The grouping of the corries into regional units results in a distinctive pattern: in the north Kiglapait group they are orientated between N35°W and N43°E and appear to be controlled to a large extent by the great convex sweep of the anorthosites to the north. However, the concentration of north-facing forms cannot be explained solely on structural grounds, though in this instance it determines the details of the orientation. The altitudes of floor/backwall junction lie within a small range, the lowest at 244 m, and the others closely conforming to the 300-m contour.

The south Kiglapait group (Figures 2 and 3) face the southwest. Individual orientations vary from N85°W to due south. In comparison with

*Eskimo for "dog-teeth."

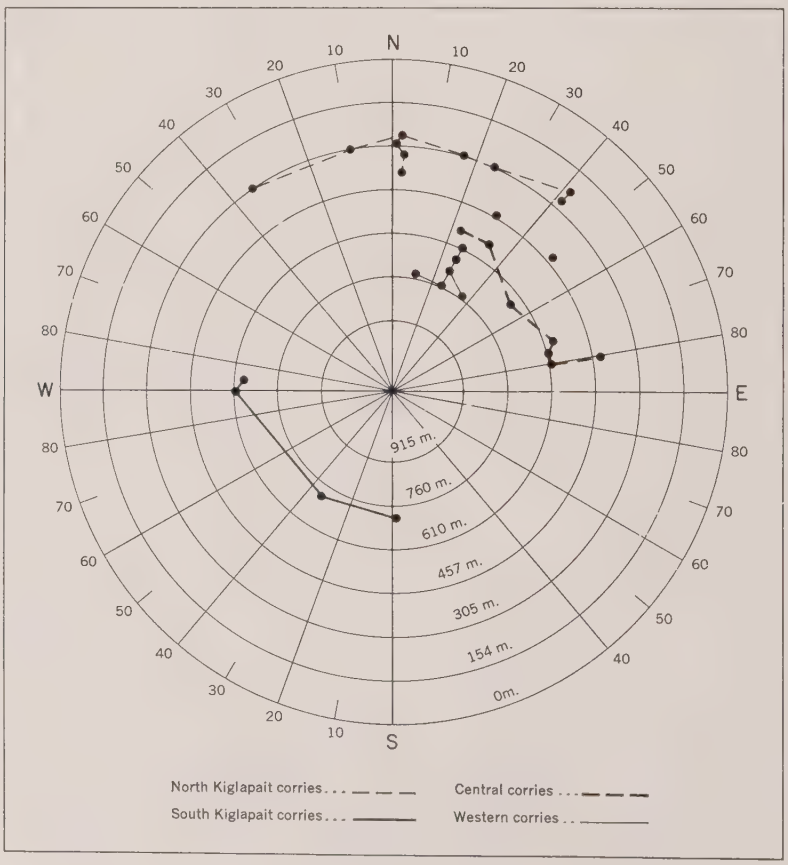

FIGURE 3

Orientation and height of the corrie floor/backwall junction with the four regional corrie groups distinguished. A pattern of increasing rigidity in orientation and height appears in an east-to-west line associated with the decrease of relative height and the limit of continuous snow cover.

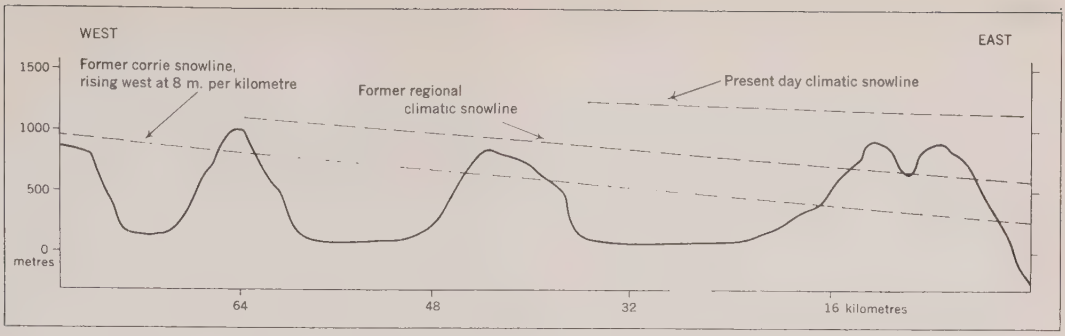

FIGURE 4. Diagrammatic representation of some climatic gradients emerging from the study.

the north Kiglapait corries they all lie at a much higher altitude, between 610 and 760 m.

The third group, referred to as the central corries, has a different pattern from those to the east. Basically Figure 2 indicates that as a group they are more rigidly orientated, varying between N22°E and N80°E, and it also shows that the corrie floor/backwall altitude varies from 428 to 670 m, with a concentration at about 610 m.

The final grouping, the western corries, are noticeably more restricted in their orientation and altitude range: the six corries all face between N10°E and N39°E and their altitude ranges from 640 to 760 m. This group lies along an east-west line with the north Kiglapait corries and a comparison of their average altitudes suggests a rise towards the west at 9 m per kilometre (Figure 4). This might not be a steady rise.

The morphology of the corries when compared with that in the Torngat Mountains (Tanner, 1944), the Rondane (Strøm, 1945) and Jotunheimen (Ahlmann, 1922) is simple and the forms are rather small. Nowhere in the area can a valley-head corrie be observed, except possibly on the south side of Man O'War Peak; in the rest of the area the corries occupy valley-side positions or, in the case of the north Kiglapait complex, they occur on the flanks of a mountain block. The abrupt and often precipitous western limit of the glaciated valleys, marking the junction of the *Valley* and *Inland Plateau* zones, might well be a glacial modification of a pre-glacial step (King, 1959). Manley (1959) has estimated the general ratio of the height of the backwall to the length of the corrie floor in Britain to be between 1:2.8 to 1:3.1. It is related, in Manley's view, to the eddying effect of strong winds. In the northern Nain-Okak section the ratio is lower; the Kiglapait corries average 1:2.1 and a similar ratio applies to the Mt. Aupalukitak corrie. Whether these figures reflect the relative youthfulness of these glacial forms or whether the ratio is climatically conditioned cannot as yet be answered. If the area is classified within the cycle of mountain glaciation (Hobbs, 1910) then it has to be termed youthful. Only in the north Kiglapait corries has the effect been to sharpen relief.

During the 1960 field season only three corries within the central group were visited. They are incised into northeastern flanks of mountains rising to 915 m, and all exhibit several features in common including a series of small arcuate corrie moraines, which implies that the corries were active during a late-glacial phase. The outer series of moraines extend down to 350 m above sea level and were formed shortly after the separation of the valley and corrie glaciers. A later series of moraines was found near the backwall at elevations of approximately 490 m above sea level. They are not fresh and the development of crustaceous lichens precludes any argument that they are datable to the "little ice age." Ninety-six kilometres to the north, Tomlinson (1962) has reported small corrie moraines believed to be younger than 200 years; farther north again in the Torngat Mountains small corrie glaciers are retreating from a series of recent moraines.

The corrie floor/backwall junction lies in nearly all cases slightly below the estimated level of the Saglek outlet glaciers and the corrie glaciers must have coalesced with these main trunk glaciers. In one corrie, a high level lateral moraine slopes out from the corrie and then turns sharply along the valley side; it indicates the presence of a trunk glacier flowing transversely to the corrie at 520 m above sea level.

FACTORS INFLUENCING CORRIE ORIENTATION

Corrie formation and altitude and orientation depend on the incidence of both vertical and hori-

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zontal space during the various glacial phases; the incidence of space is conditioned by two variables, (a) inclination of the glacial limit and (b) character of the relief (Svensson, 1959). The orientation is controlled by (a) the prevailing wind direction, (b) the effect of insolation and (c) structure. In the light of these controls an attempt is made to explain the distribution of the corries within the study area. The most noticeable point is the progressive decline in the freedom of orientation of the corries from east to west: in the far east the corries occupy two heights and orientation zones, the north Kiglapait corries lie with their backwall/floor junction at 398 m to 260 m above sea level and are orientated towards the north; the south Kiglapait corries, however, lie at approximately 755 m above sea level and face the south and west. Ahlmann (1922), Lewis (1938), Strøm (1945), Svensson (1959) and Manley (1959) stress the effect of wind drifting on corrie formation. There is a general tendency for corries to exist on the leeward slopes of mountains; this conclusion is a useful tool in an examination of climatic factors operative during periods of corrie activity. The dominant orientation of the Nain-Okak corries is toward the north and east and it is postulated that this orientation was the result of drifting by prevailing southwest winds, but with this exposure insolation was probably also very important. Today the prevailing winds are from the northwest and, as a result, snowdrifts are mainly observed on the southeast slopes. The orientation of the south Kiglapait corries is explained by their greater altitude which would make for lower temperatures, sufficient compensation for the unfavourable exposure. The past temperature difference between the corrie level in the north Kiglapait series and those in the south probably amounted to approximately 2°C. This argument presupposes that precipitation was equal on all sides, which was probably not so. With increased drifting on the northwestern slopes the increased accumulation in these corries would give them an advantage over the windward-facing corries. The two west-facing corries are possibly windward phenomena resulting from the drifting of snow into the windward face. Two hundred kilometres to the north Løken (1964, personal communication) found a different pattern with 13, 44, 17.5 and 25.5 per cent of the corries in the NE, SE, SW and NW quadrants, respectively.

From east to west, it is apparent that there is a progressive rise of the corrie backwall/floor junction, accompanied by a restriction of the orientation. The increasing elevation of the corrie backwall/floor junction meant in turn a decrease in the land surface available for corrie glaciation and a continuation of this line, which rises westward at 43 metres per km, passes above the surface of the interior plateau and suggests a climatic snowline of approximately 1320 m over central Labrador-Ungava. Under these circumstances corrie orientation and altitude become increasingly rigid in their patterns. A close correlation is also evident between the existence of corries and the calculated area of ice-free land during the Saglek glaciation. This is clearly illustrated on Figure 3 where it can be seen that all the corries are incised into mountain masses that were ice-free at this period. This should not be taken as an implication that the corries date only from the last glaciation. The pattern of corrie distribution is obviously conditioned by the two factors outlined by Svensson; the marginal slope of the outlet glaciers as deduced from the gradient of lateral moraines, rose to the west and south; the conclusion reached from the inclination of the corrie backwall/floor junction was that the snowline was inclined westward. Thus the distribution of corries is a result of the land surface. Observations suggest that the snowline in the interior was comparable to that prevailing at the coast, and it would appear that the westward inclination of the corries was primarily controlled by summer temperatures. Svensson (1959) has observed a similar pattern in the middle Scandes, with orientation of corries being more random in the west and progressively more restricted in the east.

PRESENT DAY AND FORMER SNOWLINES

Flint (1957) suggested that the corrie snowline lies at, or slightly above, the corrie floor. The average altitudes thus give a theoretical corrie-floor surface that can provide information on the gradient and altitude of the climatic snowline of the time. It is pertinent at this point to attempt the determination of the modern climatic snowline, as this will indicate the extent of climatic change since the maximum of the Saglek glaciation.

Manley (1949) postulated that for drier, more continental areas, where Ahlmann's curve (1948) is not applicable, the climatic snowline is found where the June-September mean temperature lies below 0°C. More precisely it probably occurs at a level where the July mean is 0°C. Thus, in the Nain-Okak sector it is suggested that the snowline

lies at 1280 m above sea level. Over central Labrador-Ungava the writer (Andrews, 1961) estimated that it lay at 1840 m; these figures indicate a rather gentle westward gradient of 1.6 m/km for the present climatic snowline (Figure 4). This does not allow for the expected steepening of the line over the coastal mountains.

Recently Manley (1959) has suggested that in the English Lake district the corrie snowline probably lay three-fifths of the way between the altitude of the corrie end moraine and backwall. Thus during the formation of the 335-m corrie end moraines in the central group of the Kiglapait Mountains the snowline was possibly at 458 m and later rose to about 520 m when the inner moraines were being formed.

Former climatic snowlines may be deduced from the height relationship between them and corrie snowlines. However, once again this relationship has only been examined in maritime areas (Manley, 1959) and a correction has to be sought to allow for the greater continentality of the Labrador coast. For active, north-facing local glaciers, Manley determined that the climatic snowline lies 153 m above the local snowline. He has also suggested that semi-permanent snowbeds linger through the summer 468 m below the climatic snowline in *temperate maritime areas*. In central Labrador-Ungava, Ives (1960) suggested that the latter figure should be modified to between 763 and 825 m and similarly, by applying a correction after a study of the local corrie basins, it is proposed that the climatic snowline would lie about 244 m above that in the corries. If precipitation totals were similar to those of today then it would seem that the Kiglapait Mountains harboured local glaciers when the climatic snowline descended to 550 m. To the west the snowline would be found at about 975 m. The lowering of the snowline from the present estimate of 1280 m above sea level to 550 m above sea level—the amount necessary to initiate corrie glaciers—requires a drop of 6°C in summer temperature in this latitude. A simultaneous increase in the winter precipitation would necessitate a smaller summer temperature drop. Svensson (1959) estimated a figure of 6°C for the middle Scandes.

Løken (1962) found that in the eastern sector of the northern Torngat Mountains most corries were related to the maximum upper limit of the last glaciation; thereafter a less extensive corrie glaciation occurred and the latest phase is one of terminal moraines in front of the existing glaciers. The western corries exhibited a different pattern; they were, in fact, covered by the inland ice during the first two of these phases.

CONCLUSIONS

Considering the low summer temperatures that prevail over coastal Labrador it is rather surprising that the present corries contain only insignificant glaciers that are restricted to the Torngat Mountains. There is an obvious discrepancy between the orientation of the corries and the present prevailing winds. Furthermore, Barry (1959, 1960) shows that northwesterly flow over the northeastern area of the Labrador-Ungava peninsula results in little precipitation. At present snow drifts tend to predominate on south-facing slopes which are thus unfavourably located to survive the summer. The orientation of the corries suggests that they were initiated at a time when increased south or southwesterly flow resulted in snowdrift accumulation on north- and northeast-facing slopes. This flow would have two results: it would increase the amount of the winter precipitation (Barry, 1959), and the accumulation of snowbanks on the north- and northeast-facing slopes would decrease the effects of insolation on snowbank longevity. Even with today's air-flow pattern the results indicate that a temperature change of 6°C would induce corrie glaciation, but with an increase in precipitation, coupled with drifting to shady slopes, the necessary temperature decrease would be less. In fact, with an increase in drifting, small glaciers might be initiated even today. With northeast-facing corries insolation would also be an important factor: this can be seen within the presently glacierized areas of Baffin Island, where mapping of the orientation and state of the corrie glaciers shows ice-free corries, or 'slab-filled' corries, predominantly within the southeast quadrant. Here the main precipitation air-flows are east or southwest. Tanner (1944) considered that the dryness of northwesterly winds explained the lack of extensive present-day glacierization in the Torngat Mountains. The orientation of the corries in the northern Nain-Okak area illustrates in a classic manner the importance of the prevailing winds and the restrictions imposed on corrie development by major continental ice sheets. These factors, plus the inclination of the climatic snowline and the lower orographic snowline, results in diminishing space inland and a more rigorously defined pattern of corrie orientation. Away from the ice sheet the natural eastward gradient of the glaciers results in more potential available space, and the

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lower orographic snowline imposes less control on the siting of corries. The pattern of corrie orientations is also relevant to the problem of nivation as it is one of the processes that could produce the corrie form; with a worsening of climate, and the establishment of semi-permanent snowbanks within the corries it could lead to active nivation prior to glacierization.

In attempting to answer some of the questions posed in the field investigation it became obvious that the existing literature on the subject deals nearly exclusively with the maritime climate of northwest Europe. In Labrador and the eastern Arctic seaboard of Canada it is necessary to introduce some modifications, but these must be largely derived from theoretical considerations. There is need for investigation within the presently glacierized mountain areas.

ACKNOWLEDGMENTS

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MAJOR END MORAINES IN EASTERN AND CENTRAL ARCTIC CANADA

G. Falconer, J. D. Ives, O. H. Løken and J. T. Andrews

ABSTRACT

A system of end moraines more than 2,000 km long, has been identified by field investigation and from air photographs. It runs parallel to the northeast coast of Baffin Island approximately along the line of the fiord heads; it extends down the west coast of Melville Peninsula and across northern Keewatin and demarcates the border of a late-Wisconsin ice sheet that was centred over Foxe Basin and Hudson Bay between 8,000 and 9,000 years ago. The various units of the system are described and related radiocarbon dates are discussed. A tentative correlation with the Cochrane Readvance and with moraine units in northwestern Ontario and in the Lake Athabasca-Cree Lake area is made. The names "Cockburn Glacial Phase" and "Cockburn Moraine System" are proposed for use on a regional scale; this involves a redefinition of the Cockburn moraines of northeast Baffin Island as originally proposed by Ives and Andrews (1963).

RÉSUMÉ

On a reconnu par des travaux sur le terrain et l'examen de photographies aériennes un réseau de moraines terminales de plus de 2,000 km de longueur. Il court parallèlement à la côte nord-est de l'île Baffin et se trouve à peu près en ligne avec le fond des fiords. Il descend la côte ouest de la péninsule de Melville, traverse le Keewatin Nord et démarque la frontière de la nappe glaciaire du Wisconsin supérieur qui était centrée sur le bassin Foxe et la baie d'Hudson il y a de 8 à 9,000 ans. On y décrit les diverses unités du réseau et on fait l'analyse des datations au carbone radioactif qui s'y rapportent. On a tenté de faire la corrélation avec la récurrence de Cochrane et les moraines du nord-ouest de l'Ontario et de la région lac Athabasca-lac Cree. On propose pour usage à l'échelle régionale les noms de "Phase glaciaire Cockburn" et "Réseau de moraines Cockburn". Ceci comporte une redéfinition des moraines Cockburn du nord-est de l'île Baffin étudiées antérieurement par Ives et Andrews (1963).

INTRODUCTION

During the preparatory interpretation of trimetrogon air photographs for the "Glacial Map of Canada" (Geol. Assoc. Can., 1958) Falconer traced a conspicuous end moraine, for which the name "MacAlpine Moraine" is now proposed, which extends nearly continuously for about 800 km from southwest of MacAlpine Lake (66°40′N; 103°W) northeast toward Chantrey Inlet and beyond to Committee Bay (Figure 1). Part of this moraine is shown in generalized form by Flint (1957, p. 315) but as its nature was not then verified by actual field investigation, it was omitted during the reduction of the manuscript maps to the publishing scale of approximately 1:3,800,000.

MS submitted February, 1965.

Discovery of a major end-moraine system in Baffin Island* (Ives and Andrews, 1963) and extensive sections of end moraine on Melville Peninsula (Sim, 1960) led to speculation that they might be connected with the MacAlpine moraine of the Keewatin mainland. Thus, as an expansion of the air photograph interpretation associated with the Geographical Branch research program in Baffin Island, an attempt was made to trace possible extensions of the three major sections of moraine. Figure 1 shows the success of this attempt in a generalized form. With relatively few and minor gaps, end moraines have been traced over a distance of 2,000 km; Figure 1 shows the general extent of these and attempts to differentiate between

*The name "Cockburn" was originally applied to the entire system, although this paper proposes a much more restricted use of the term.

sections of multiple ridges and large single ridges. This paper presents descriptions of the various sections of the end-moraine system and discusses their age relationships.

THE DISTRIBUTION OF THE MORAINE SYSTEMS

Although there are great variations in prominence and form, the moraine systems described here can be traced nearly continuously along the eastern coast of Baffin Island, through parts of northwestern Baffin Island, along the west coast of Melville Peninsula, westward across the area between Committee Bay and Chantrey Inlet and, with an increasingly southwesterly trend, to within 100 km of the head of Bathurst Inlet. From that point the system can be followed southward to Back River but thereafter it becomes indistinct. It is tempting to speculate that the moraines in the Lake Athabasca-Cree Lake area some 500 to 600 km to the southwest represent a southern equivalent that may be traceable into northwestern Ontario and beyond. In order to indicate the extent and variations in form of the moraine, and as a setting for the discussion of pertinent radiocarbon dates, its various regional units are examined and illustrated in Figure 1.

SOUTHERN BAFFIN ISLAND

Two major moraines have so far been found in southern Baffin Island. One on Hall Peninsula may represent the position of a major lobe of the main ice sheet, although it might indicate the presence of an independent late-glacial ice cap. The relationship between this moraine and the second feature, a series of moraine loops situated 13 km north of the head of Frobisher Bay, is not known, nor as yet is their relationship to the major moraine system of east-central and northern Baffin Island fully understood.

CUMBERLAND PENINSULA

Mapping of the moraines and ice-flow features from air photographs indicates that two distinct morainic belts occur; the first, which roughly parallels the coast, is probably a continuation of the Cockburn moraines related to a large western ice sheet, the other, probably to a "proto-Penny Ice Cap". The Cockburn system (*sensu lato*) extends as lateral moraines and end-moraine loops into the valleys north of the Penny Ice Cap, whereas south of the ice cap a major end moraine extends from Millut Bay (66°38′N, 67°35′W to 67°00′N, 67°42′W), a distance of 32 km (Figure 1). Air photograph interpretation shows no visible connection between this moraine and another which lies six km north and which was formed at the margin of an ice lobe moving southward. Twenty-six km north again another moraine parallels it before turning to become orientated parallel with the Penny Ice Cap (Figure 2). The trend of distinct flow features related to these moraines suggests that the centre of dispersal of the proto-Penny Ice Cap lay north and west of the present crest. In both cases the moraines disappear beneath the present ice-cap margin. They are represented by a series of small ridges inside a main outer moraine and together constitute a three-km-wide belt.

THE "COCKBURN MORAINES" (*sensu lato*) OF EASTERN BAFFIN ISLAND

Maps showing the generalized distribution of the major moraine system in eastern Baffin Island have already been published (Ives and Andrews, 1963, Figures 1 and 2). The main section of the moraines occurs as a 10-to-26-km-wide belt of closely spaced ridges with individual members varying from six to 46 metres in height (Figure 3). The moraines have been found without exception along the southwest margin of the coastal mountains east and northeast of the Barnes Ice Cap and only slightly less continuously inland from Home Bay, over a total distance of about 480 km.

The outermost of the end moraines lie on the high interfiord mountain flanks and descend into and along the fiords as lateral moraines, while the inner moraines lie mainly on the upland plateau at about 600 metres above sea level.

NORTHERN BAFFIN ISLAND

The moraine belts along the margin of the coastal mountains northeast and north of the Barnes Ice Cap can be traced for an additional 160 km westward from North Arm past the heads of Pacquet Bay and Tay Sound to 24 km beyond Milne Inlet in latitude 72°N. In the plateau area between Milne Inlet and the head of Admiralty Inlet they have not been found, although flights of glacial drainage channels indicate the position of decaying ice tongues that occupied the wide valleys dissecting the sedimentary plateaux in the southern part of Borden Peninsula. Southwest of Admiralty Inlet, along both north and south shores of Bernier Bay and Berlinguet Inlet very well developed morainic belts can be traced; they outline the

110°
90°
VISCOUNT MELVILLE SOUND
8
6
70°
Melville
Peninsula
11
10
9
Mac Alpine Lake
65°
KEEWATIN
110°
90°

FIGURE 1. Major Moraines in Eastern and Central Arctic Canada

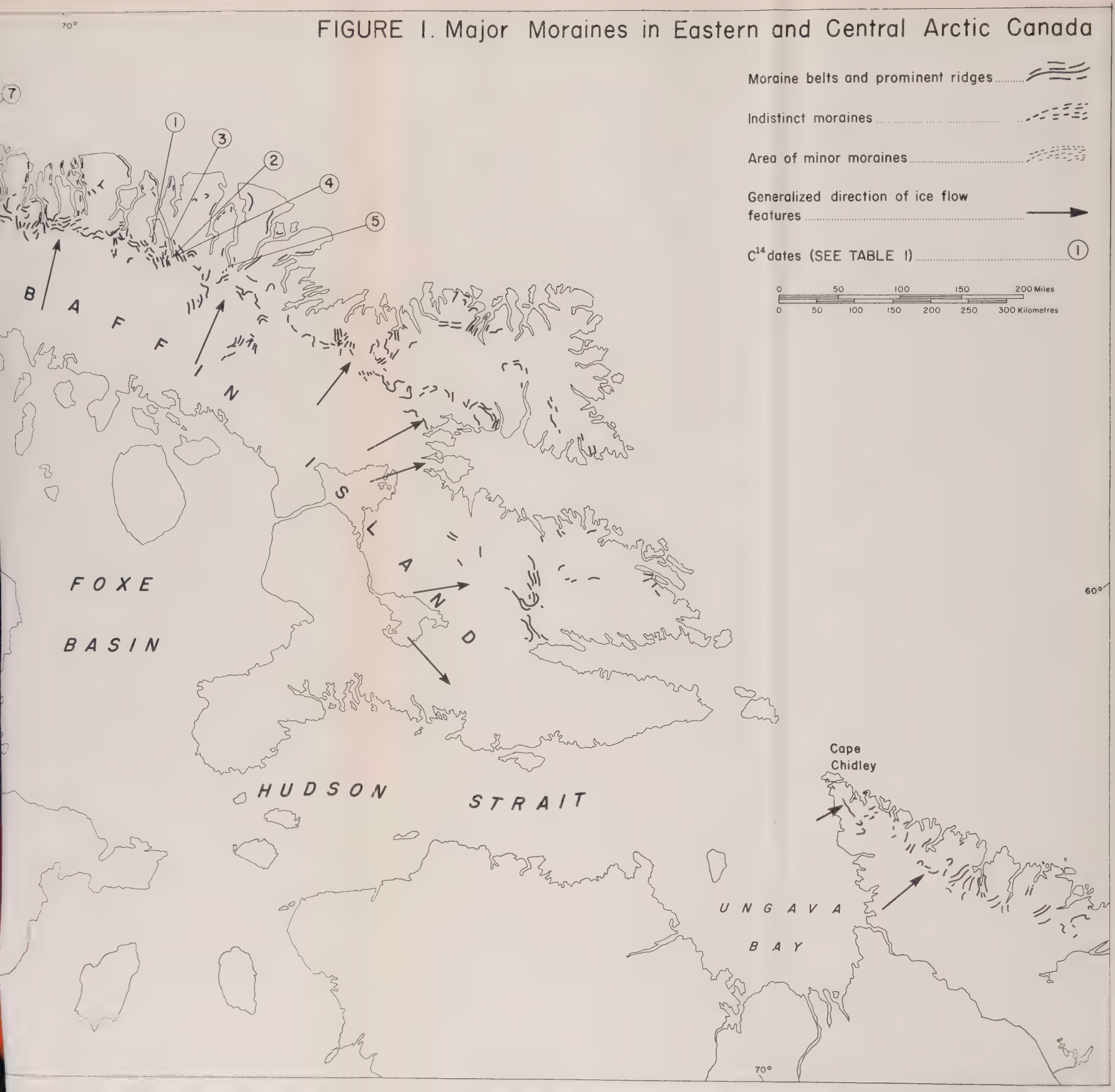

FIGURE 2. Air photograph of end moraines near the northwestern edge of the Penny Ice Cap, Baffin Island
Photo: National Airphoto Library No. A17038-96, 16 July 1961.

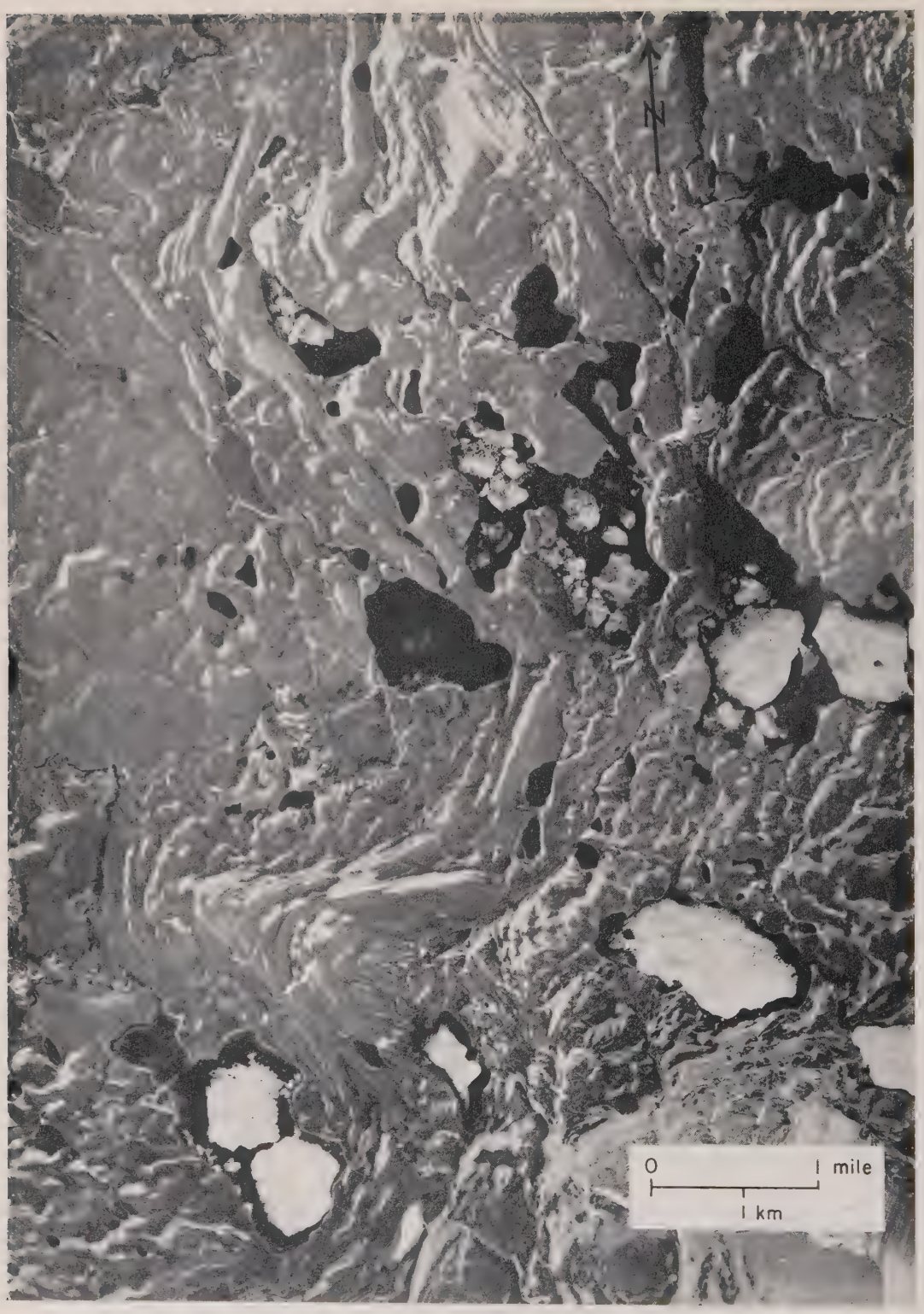

FIGURE 3. Air photograph of part of end moraine system east of Conn and Bieler lakes, northeast Baffin Island. Photo: National Airphoto Library No. A17047-156, 24 July 1961.

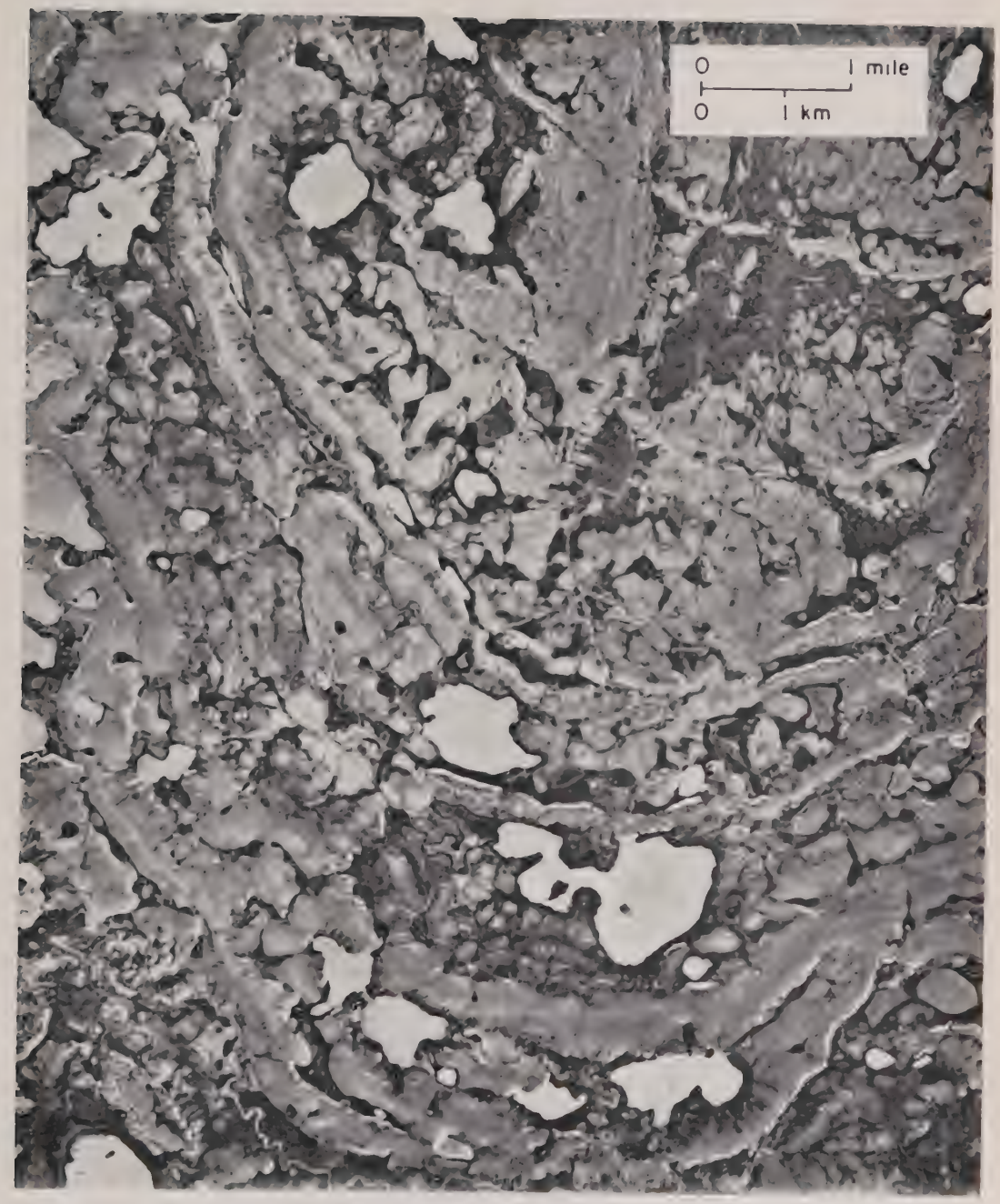

FIGURE 4. Air photograph of well developed end moraines southeast of Bernier Bay, northwest Baffin Island. Photo: National Airphoto Library No. A16125-21, 1 July 1958.

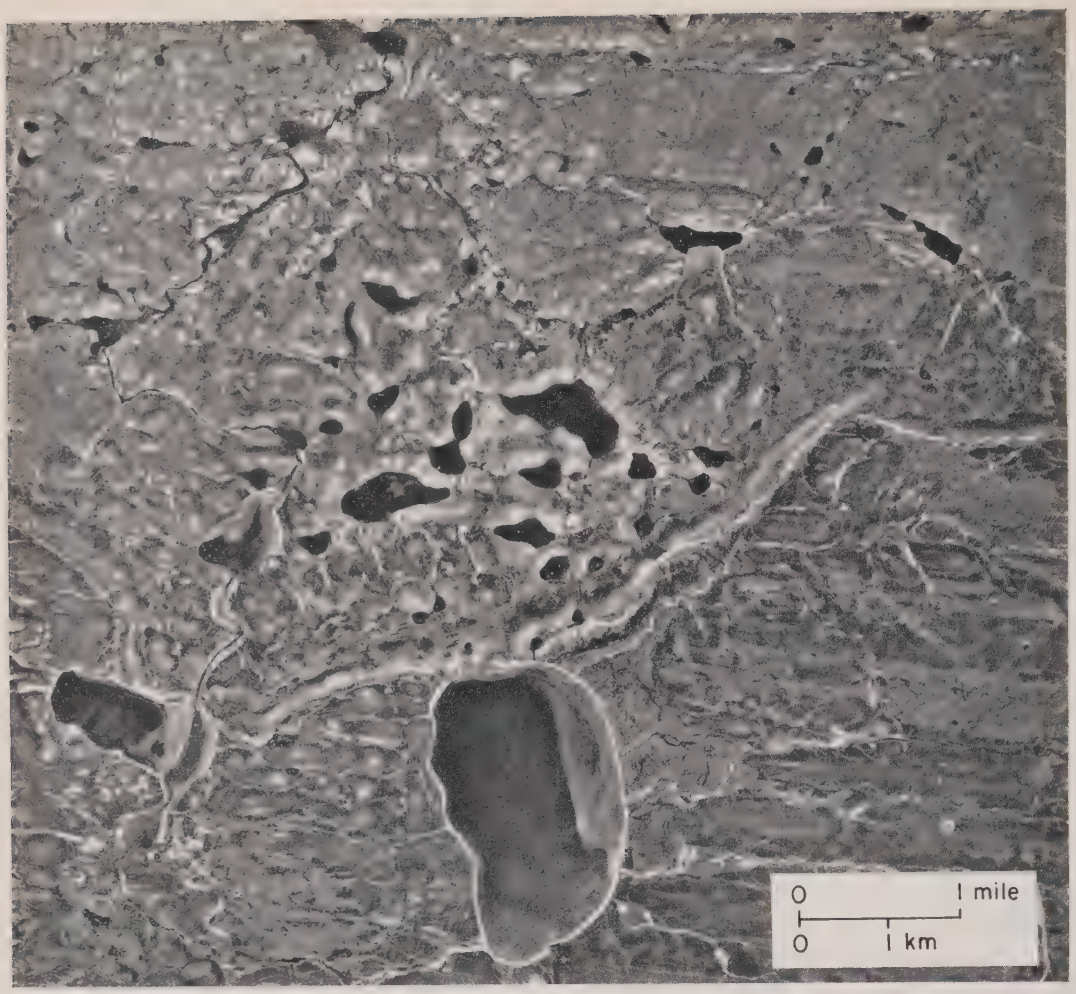

FIGURE 5. Air photograph of Cockburn end moraine in northwest Melville Peninsula. Ice-flow features north of the prominent ridge indicate latest movement from the northeast.

Photo: National Airphoto Library No. A16266-2, 16 August 1958.

position of a large ice lobe that flowed westward. Ice-flow features and drumlins indicate an over-all westward movement south of Berlinguet Inlet with local lateral expansion of the lobe forming loops and embayments (Figure 4). A zone of southeast to northwest trending drumlinoid forms some eight km southeast of Bell Bay, truncated by former marine action on the west, suggests that the lobe of ice flowing westward into Berlinguet Inlet had its source in the upper reaches of the Gifford River. Blackadar (1958), however, interprets the drumlinoid features east of Bell Bay as evidence of ice movement from northwest to southeast.

The Bernier Bay-Berlinguet Inlet moraines are most clearly developed in a 160-km belt along the south side of these water bodies. Figure 4 shows an example of this development south of the isthmus between Berlinguet Inlet and Bernier Bay. On the north side of Bernier Bay and Berlinguet Inlet the situation is complicated by the probable former existence of a separate ice cap on Brodeur Peninsula. Thus the moraine belt there has fewer distinct loops and may prove to be partly interlobate in character. Ice-flow features trending northeast to southwest in the southern part of Brodeur Peninsula can be seen on air photographs 16 km west of Janes Creek bounded on the south by morainic loops. Local belts of till and sometimes small moraine loops along the west coast of Brodeur Peninsula presumably were formed by

the same local ice centre. Relatively minor and indistinct moraine-like features on the east side of the peninsula extending as far north as latitude 72°15′N may represent the other side of the ice cap, or alternatively may have been formed at the margin of ice occupying Admiralty Inlet.

Twenty-four km north of Agu Bay drumlinoids and till concentrations on valley sides indicate a local lobe of ice moving from the northeast, but the best indications of such movement north of Hecla and Fury Strait occurs north of Autridge Bay, from which area well developed till flutings, drumlinoids and crag-and-tail deposits can be traced east to Sikosak Bay. West of this zone of flutings, large moraines are developed on the valley sides but merge into an indistinct band of till on approaching the abrupt bend of the Gifford River. The moraines west of Autridge Bay seem to be the northern equivalent of the features on Melville Peninsula described below.

MELVILLE PENINSULA

The continuation of the Cockburn moraine system into northwestern Baffin Island indicated that their equivalent might also be found on Melville Peninsula. Examination of the recent vertical photographs at a scale of 1:60,000 led to the location of an impressive end moraine (Figure 5) at the northwestern tip of the peninsula. Flow features adjacent to the moraine (Figure 1) imply that it has been formed at the margin of an ice lobe moving southwestward across northwestern Melville Peninsula, with a source area on northern Baffin Island. The Melville moraine differs from the Cockburn moraine system in that it is generally represented by a single large feature rather than a belt of ridges. The moraine trends southeast to a point near Encampment Bay (69°30′N, 85°15′W) for a distance of about 58 km: it then turns west in 69°30′N toward Franklin Bay. Hereafter it can be traced as a conspicuous feature for 40 km to the north shore of Garry Bay. The moraine digitates in accordance with the major valleys and there can be no doubt that it was formed at the margin of ice moving westward across Melville Peninsula. The change in orientation between the Encampment Bay moraine and the north-south trending moraine inland from Franklin Bay probably reflects a difference in local ice-dispersal centres, with the former moraine originating from a centre over the Gifford River in northern Baffin Island and the latter from a centre due east of the peninsula, probably over Foxe Basin. Sim (1960) presented strong evidence for a major east-to-west ice movement across northern Melville Peninsula, and this was further substantiated by analysis of the carbonate content of a series of till samples (Andrews and Sim, 1964). The results indicated conclusively that movement had been westward across the limestone outcrop on the east side of the peninsula.

A similar, though less pronounced change was noticed on the south side of Garry Bay where the moraine continues along longitude 85°20′W (Figure 1). The north-to-south trend is interrupted at about latitude 68°30′N by a moraine orientated northeast to southwest which then trends southward parallel to the east side of Committee Bay to a point near Cape McTavish (67°40′N). In this area Sim (1960) has described it as a kame moraine and has illustrated its form and composition; however, the present writers believe that the Melville Peninsula moraine was not deposited by a stagnant ice cap situated over Committee Bay; its relationship to the valleys implies that it owes its origin to westward moving ice.

Arctic Mainland Coast

The moraine system in this section is a direct continuation of the Melville Peninsula moraines and can be followed to beyond MacAlpine Lake.

A major east-west ridge lies 16 km north of Point Hargrave on the west side of Committee Bay (67°25′N; 87°40′W). It can be traced, with minor breaks, for about 250 km to the headwaters of the Hayes River in longitude 93°20′W. The continuity of the moraine is interrupted in the vicinity of Chantrey Inlet, where the shores and coastal plain to the west were inundated by the late-glacial marine transgression. The presence of short stretches of successive end moraines and large numbers of de Geer moraines (Hoppe, 1959) mainly on the west side of the inlet and south of McLoughlin Bay (long. 98°30′W) indicates the existence of a calving bay during deglacierization.

There is a 140-km break in the continuity of the moraine between the western side of Chantrey Inlet and its recommencement about longitude 100°W. This correlation is based upon the alignment of the two sections and the absence of other comparable features. The western section can be followed southwest from this point for about 56 km: in places it is represented by a single, broad ridge, this again contrasting with the complex moraine system of Baffin Island. East of Perry River it disappears and the land drops below the marine limit: beaches and other features indicate

that the valley was occupied by the sea during the initial deglacierization. Between Perry River and MacAlpine Lake raised deltas, some associated with eskers, are present along this section of the moraine and indicate that it was deposited in association with the sea. Beyond MacAlpine Lake, where it is prominently developed, it swings more nearly southward to run parallel with the Ellice River, and its distal side is most strikingly marked by a series of delta fans.

In the upper Back River area the moraine eventually becomes discontinuous. However, it can be traced quite easily for 96 km, bearing southwest then south, to the banks of the Back River where it consists of a one-km belt with esker fans conspicuously marking the distal side. It is very difficult to trace south of Back River and north of Moraine Lake but possible sections are marked on Figure 1. Here a series of delta fans indicate the position of the ice margin. No evidence of the moraine could be found in the Artillery Lake region and it seems probable that the ice margin was fronting one of a series of glacial lakes, abandoned shorelines of which are apparent on air photographs of the Thelon and Dubawnt River valleys.

Possible Southern Continuations

Air photograph interpretation was undertaken for the area southwest of the Thelon and Dubawnt glacial lakes in an attempt to link the northern moraines with possible equivalents in the Prairie provinces and northern Ontario.

The Glacial Map of Canada shows moraines trending southeast to northwest in the area southwest of Cree Lake. They were traced farther northwestward to where they crossed Lake Athabasca just east of the 111th parallel. In the opposite direction, however, they become indistinct and, south of Reindeer Lake, difficult to trace. The possibility that their eastern equivalents lie in the moraines east and southeast of God's Lake and Island Lake (Prest, 1963) in eastern Manitoba and northwestern Ontario, therefore, remains open.

In the Torngat Mountains of Labrador-Ungava moraines, both east and west of the watershed, indicate the former presence of a major ice body over Ungava Bay (Ives, 1957, 1958; Løken, 1962, 1964). The earliest, Noodleook moraine phase, and the latest, Sheppard moraine phase (Løken, 1964) might be compared with outer and inner sections of the eastern Baffin Island moraines. Moraine systems have also been traced southward from the Torngat Mountains into the Nain-Okak Section of the Labrador coast (Tomlinson, 1959; Andrews, 1963).

RADIOCARBON DATES AND THE AGE OF THE MORAINE SYSTEM

The most significant feature of the various stretches of moraine described above is that, taken together, they form a system remarkable for its length, continuity and degree of development. The outline suggestively depicts the northern half of the perimeter of an ice sheet of sub-continental proportions centred upon Foxe Basin and Hudson Bay. Such a consideration brings into focus two major questions: what are the ages of the specific moraine sections that make up the system—are they contemporaneous? and, if this system depicts the perimeter of the northern half of an ice sheet, what was the location of its southern margin? The second question involves field work and evaluation of field evidence far beyond the area principally under discussion. It is therefore proposed to place emphasis on the first question.

That the northern arctic mainland coast, lying north of the end moraine system, was ice-free 10,000 years ago is well documented by Craig and Fyles (1960), Craig (1961, 1964) and Blake (1963). However, Craig and Fyles (1960, p. 7) go on to indicate a subsequent "more or less orderly retreat of the ice margin toward the interior of the Shield", until final dissolution occurred about 7,000 years ago in a linear zone termed the Keewatin ice divide. Craig (1961) has mapped short stretches of the moraine system, but initially discounted their significance as they were situated in the central zone of the Wisconsin ice sheet, within which it was thought that the ice margin retreated rapidly and regularly with no pronounced periods of marginal fluctuation.

Blake (1963) later mapped sections of the MacAlpine moraine between Bathurst and Chantrey inlets and suggested that individual stretches were probably formed at the same time. Blake's conclusions relating to the age of the MacAlpine moraine are discussed below.

From the foregoing commentary it can be seen that the present writers, on the basis of physical extent and continuity, suggest that the moraine system is one and that it resulted from an important glacial episode in the Canadian Arctic hitherto undocumented (cf Falconer, Andrews and Ives, 1965). It is clearly understood that some sections of the moraine are morphologically simple and the product of a relatively short episode; other

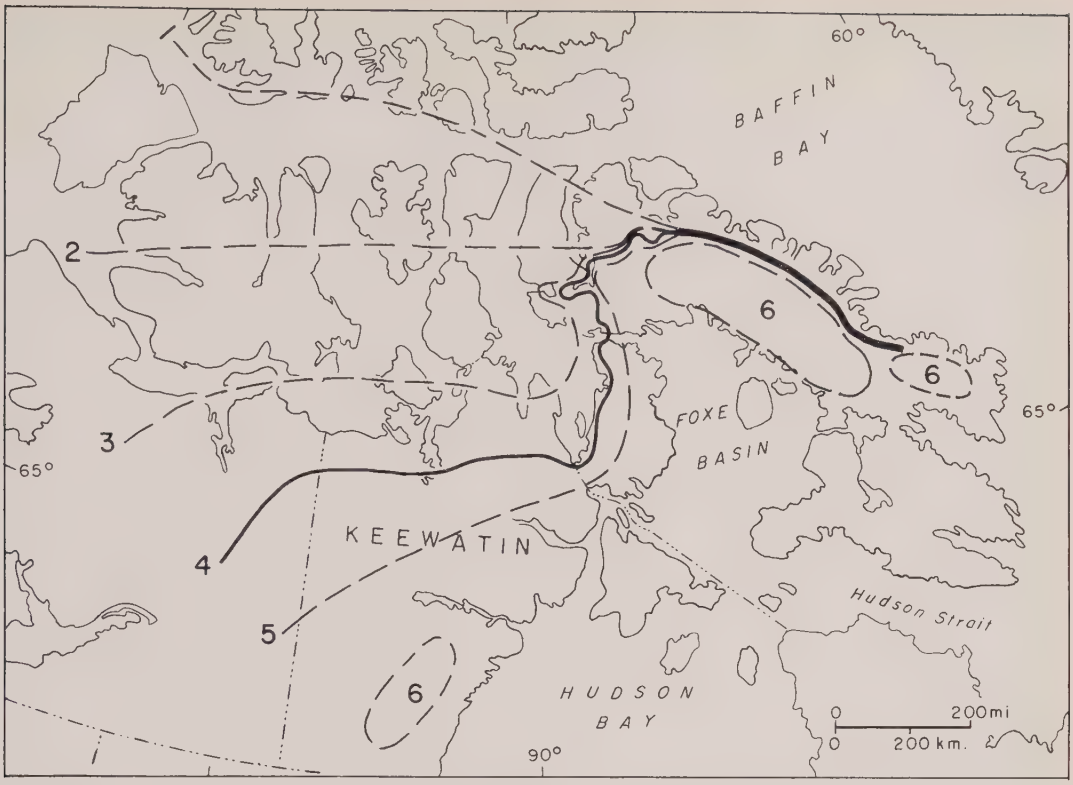

FIGURE 6. Schematic representation of late-Wisconsin deglaciation in the central and eastern Canadian Arctic. Phase 4 is the Cockburn Phase and the heavy line coincides with actual end moraines. Phases 1, 2, 3 and 5 are purely hypothetical and probably cannot be substantiated by specific field evidence. Phase 6 in Keewatin represents imminent completion of deglaciation along the Keewatin ice divide about 7,500 years ago; in Baffin Island glaciation was still extensive.

sections, notably the east Baffin section, are extremely complex and the product of several episodes extending over a very considerable period of time. A major objective of this paper is to establish that, in a broad sense, a trace of the entire system delineated the approximate boundary of a subcontinental ice sheet at one particular point in time. A second objective is to provide a realistic estimate of its age on the basis of radiocarbon dating. As these two objectives are closely interrelated and depend absolutely on the success of the dating attempts, the available radiocarbon dates are now considered in detail.

EASTERN BAFFIN ISLAND FIORDS

Two separate phases were originally designated for the Cockburn moraine system (Ives and Andrews, 1963). The outer end moraines occur on the high, west-facing inter-fiord mountain flanks and descend along the fiords towards Baffin Bay as lateral moraines, their termini being submarine and, so far, unmapped; the inner moraines lie predominantly back from the fiord heads on the uplands at about 600 metres above sea level. The outer and inner moraines merge into a narrow belt of complex ridges 10 to 15 km wide between the fiords; their division into a Cockburn I and a Cockburn II phase was tentative and was introduced primarily for descriptive purposes. However, such differentiation may have been premature as no stratigraphic determination nor absolute dating of the two phases has yet been accomplished. These upland areas between the fiords obviously formed a topographic barrier against which the northeast margin of the ice sheet abutted: in contrast the fiords became major outlet ducts for continental ice which, at various times, penetrated into Baffin Bay. Thus the fiord sides provide a very different picture and where conditions are topographically favourable the moraine system, represented principally by sections of lateral ridges, extends over a considerable distance.

Marine mollusc shells were collected by Ives in 1963 near the head of Walker Arm (lat. 70°15′N) at 28 metres above sea level, or approximately 32 metres below the local marine limit. The shells were gathered from residual mounds of marine silts and yielded a radiocarbon age of 5,560 ± 250 years (I-1243). Their age indicates that maximum marine transgression occurred at least 5,600 years ago and that the outer Cockburn moraines, which terminate far to seaward of the shell locality, must, therefore, be appreciably older than 5,600 years. A second collection of shells from the head of Sam Ford Fiord (lat. 70°02′N), at an altitude of 40 metres, yielded a radiocarbon age of 5,390 ± 150 years (I-1321), which is consistent with this deduction. The two dates only provide a minimum age for the outer Cockburn moraines; on this basis, therefore, the inner moraines could be younger or older than the shells.

In 1964 Løken and Smith made collections of mollusc shells at the heads of Sam Ford and Inugsuin fiords. The Sam Ford collections are particularly significant. Sample OHL-64-7S (I-1553) was collected on the northeast side of the fiord 23 km from its head at a height of 63 metres. It was taken one metre below an outwash delta formed by drainage along the distal side of a lateral moraine. The shells are believed to be contemporaneous with the moraine, but may have been ploughed up by the advancing ice body and redeposited. The radiocarbon age of 7,500 ± 200 years indicates in any event the maximum date of a readvance of the outlet glacier to a point 23 km beyond the fiord head. Several groups of fresh looking readvance moraines were found along the inner part of Sam Ford Fiord and the one dated by sample OHL-64-7S (I-1553) is the oldest but two of these groups. Older fluctuations are thus represented in the immediate vicinity.

The second sample (JES-64-1S; I-1556) was taken from an altitude of 46 metres approximately two km south of the fiord head and has a radiocarbon age of 6,200 ± 140 years. A lateral moraine between the sample locality and the fiord head is associated with a sea level of 50 metres, only four metres above the dated sample and it is argued that this moraine cannot be much older than the shell sample. The outlet glacier had thus retreated a distance of 23 km over a period not exceeding 1,300 years.

The observations from Sam Ford Fiord have been substantiated by observations at the head of Inugsuin Fiord where a shell sample (OHL-64-9S; I-1554) gave a radiocarbon date of 7,030 ± 190 years. This sample was taken on the distal side of two groups of end moraines, while it lies on the proximal side of four groups. It is therefore to be expected that the age should be intermediate between the two dates from Sam Ford Fiord. The difference in the glacial history of the two fiords is due to the much greater inland penetration of Sam Ford Fiord and to the fact that this fiord continues southwestward as a major valley while there is only a small valley leading inland from the head of Inugsuin Fiord.

NORTH BAFFIN ISLAND INLETS

West of Koluktoo Bay, in Milne Inlet (lat. 72°04′) a large morainic loop, composed predominantly of limestone-rich till derived from the sedimentary rocks farther south, was deposited by a tongue of ice pushing through a bordering range of granite-gneiss hills. This moraine extends eastward to Milne Inlet, and elements of the same complex can be traced as far as Tay Sound. Other moraine belts occur farther south and while the whole series forms part of the general Cockburn system (*sensu lato*), the Koluktoo ridge, because of its outer position, is one of the older moraines in the area. Fragments of mollusc shells were collected from a gap in the outer part of the moraine loop (Figure 7). The shells were collected at 61 metres above sea level and proved to be 7,930 ± 300 years old (I-1246). They were found as fragments on the surface of, and within, a thin, discontinuous deposit of silt that in turn rested upon the morainic material. Delta fans adjoin the moraine and are associated with a distinct local marine limit at 73 metres above present sea level; it seems likely that the glacier terminated in tidewater and that the molluscs invaded the area shortly after retreat of the ice front.

A series of looped terminal moraines reach the sea on the west side of Tay Sound (lat. 72°00′N, long. 79°15′W) 69 km due east of Koluktoo Bay. In 1962 Falconer collected marine shells 76 metres above sea level from the surface of a feature interpreted as a marine-modified end moraine. Precise levelling indicates that the local marine limit lies 89 metres above present sea level and the age of the shells (8,350 ± 300 years; I-724) gives a good approximation of the date of maximum transgression. This date substantiates the Koluktoo Bay date and leads to the conclusion that the moraines are probably slightly more than 8,400 years old.

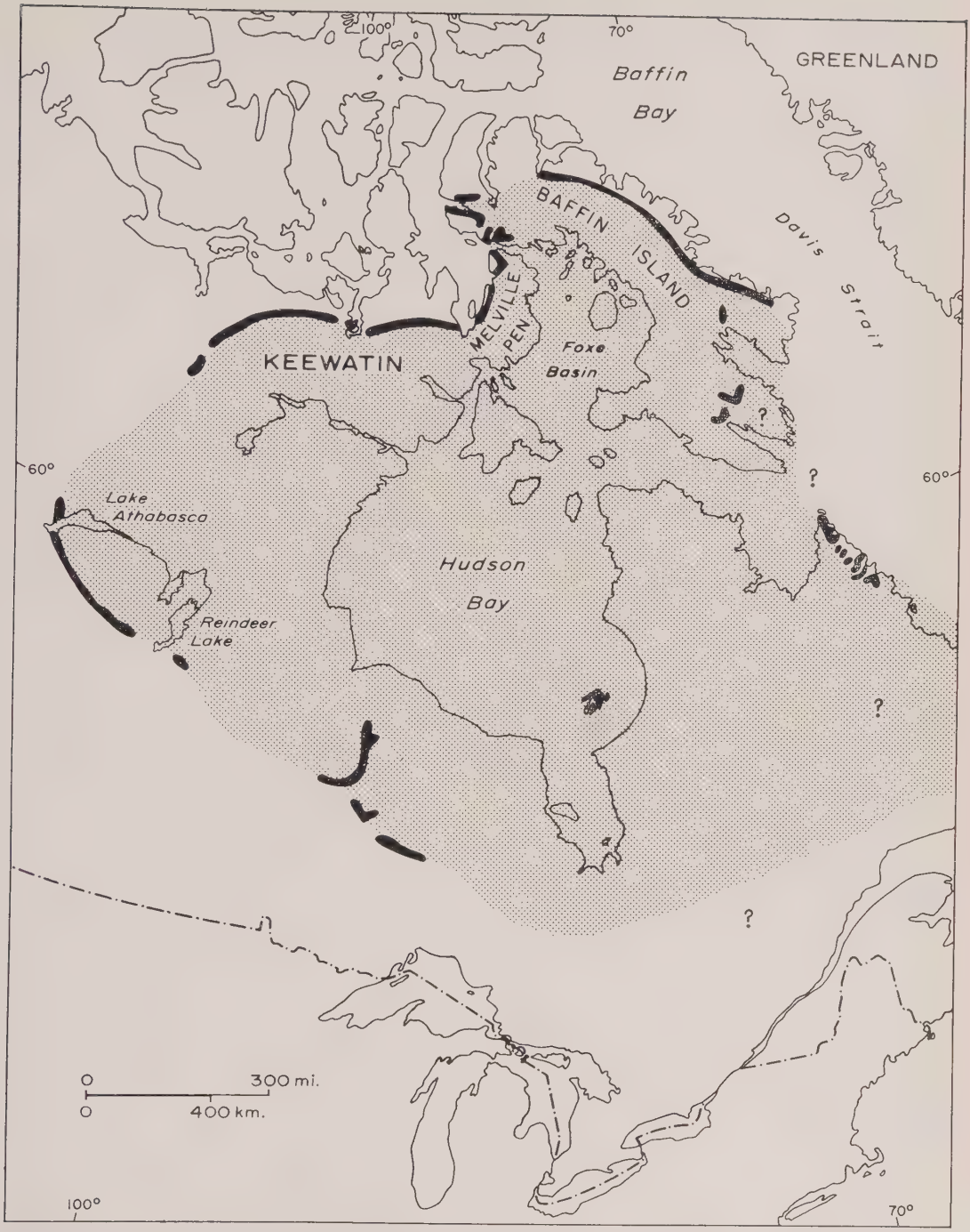

FIGURE 7. Generalized outline of the Cockburn moraine system and the perimeter of the ice sheet 8,000 to 9,000 years ago, representing the Cockburn Glacial Phase. At this scale some independent centres of glaciation have been merged into the main ice sheet while others have been omitted.

In 1961 Falconer collected a sample from the lower part of a five-metre-thick undisturbed peat deposit lying between 40 and 50 metres above sea level and west of Arctic Bay in northern Admiralty Inlet. The peat yielded an age of 9,360 ± 230 years (I-1315) which indicates that outlet glaciers from the Baffin mainland to the south had retreated from the locality prior to the deposition of the peat. This date naturally provides no evidence for use in determining the age of the moraines, although it does place an outer limit on the extent of the outlet glaciers of this period.

KEEWATIN MAINLAND

In the Chantrey Inlet area Craig (1961) has mapped the approximate limit of marine submergence. A trace of the end moraines, mapped by the writers and superimposed upon Craig's plot of the marine limit, shows that the two features coincide near the mouth of Hayes River where Craig reports the height of the marine limit at about 164 metres and may be approximately related in age. Shells obtained by Craig from localities near Pelly Bay give minimum dates of 8,700 ± 140 years (GSC-47) and 8,870 ± 140 (GSC-44) years for the marine limit and while it is probably time-transgressive over such a large area the results are of significance to the problem of dating the moraine system and agree in general with the Tay Sound-Koluktoo Bay data.

Near MacAlpine Lake, some 200 km east of the head of Bathurst Inlet, Blake (1963) obtained shells that are 8,160 ± 140 years old (GSC-110) from an elevation of 183 metres within 16 metres of the marine limit. He concluded that the margin of the ice sheet rested against the proximal side of the moraine when the shells were deposited on the distal side although he does not discuss the presence or absence of raised marine shore features on the proximal side. He concluded that, because of its impressive dimensions, the moraine took a considerable time to form.

DISCUSSION

The radiocarbon ages of mollusc shells support the contention that the northern margin of the residual late-Wisconsin ice sheet stood against the general line of an extensive moraine system between 8,000 and 9,000 years ago. While it is probable that the Keewatin and Melville Peninsula sections were formed within this relatively narrow span of time it cannot be claimed that a single ice marginal position, as represented by a specific morainic ridge, can be followed throughout the system into Baffin Island. The contrasts in degree of development of the moraine system along its length are highly significant and warrant further discussion.

The MacAlpine and Melville Peninsula sections are generally represented by a relatively simple, massive ridge, often associated with glacio-fluvial deposits. In northern and eastern Baffin Island, however, end moraines occupy a broad tract of country. It is highly probable that this moraine complex represents a prolonged and complicated history. Under these circumstances it is proposed that the term "Cockburn" be restricted to the moraines constructed between 8,000 and 9,000 years ago so that the single "Cockburn Phase" will represent the late-Wisconsin residual ice sheet as depicted on Figure 1. The general outline of the northern and northeastern margins of the "Cockburn Ice Sheet" are adequately represented, but the detailed outline, in Baffin Island at least, requires precise tracing and dating of individual ridges in the irregular fiord and mountain terrain.

Table 1

Radiocarbon Dates Associated with Cockburn Moraine System

Locality Figure 1	Height Above Datum (metres)	Laboratory Number	Locality	Age in Years	Collector and Date
1	28	I-1243	East Baffin	5,560 ± 250	J. D. Ives (1963)
2	40	I-1321	" "	5,390 ± 150	J. D. Ives (1963)
3	63	I-1553	" "	7,500 ± 200	O. H. Løken (1964)
4	50	I-1556	" "	6,240 ± 140	J. E. Smith (1964)
5	26	I-1554	" "	7,030 ± 190	O. H. Løken (1964)
6	61	I-1246	North Baffin	7,930 ± 300	G. Falconer (1963)
7	76	I-724	" "	8,350 ± 300	G. Falconer (1962)
8	40-50	I-1315	" "	9,360 ± 230	G. Falconer (1961)
9	200	GSC-110	Keewatin	8,160 ± 140	W. Blake (1963)
10	165	GSC-47	"	8,700 ± 140	B. Craig (1963)
11	157	GSC-44	"	8,870 ± 140	B. Craig (1963)

With this restricted definition of the term "Cockburn" the lateral moraine, dated by Løken as less than 7,500 years old, is younger than the Cockburn moraines. The Cockburn phase in Baffin Island, therefore, was characterized by glacial inundation of most of the island, with the eastern mountain rim rising as a topographic barrier: the outlet glaciers would penetrate to tide-water along most of the fiords, and Sam Ford Fiord, and possibly others, would have their inner sections completely filled with glaciers.

The contrast in moraine development between Baffin Island, and Keewatin and Melville Peninsula, is partly a reflection of their great topographic differences. It has been established that Baffin Island was still largely ice-covered as recently as 7,000 years ago (Ives and Andrews, 1963; Ives, 1964) by which time the entire Keewatin region was ice-free (Craig and Fyles, 1960; Lee, 1959); it is also known from dates on marine shells (Lee, 1960; 7,875 ± 200 GSC-14; 7,280 ± 50, GRO-1698) that the sea had disrupted the ice sheet and had penetrated to the southern shores of Hudson Bay: thus, withdrawal of the ice margin from the MacAlpine moraine was very rapid, as the 500-km distance between it and the area of the Keewatin ice divide was uncovered within about 1,500 years. During the same interval Melville Peninsula and Foxe Basin were cleared except for Baffin ice which continued to cross sections of the southwest coast of Baffin Island into the sea. During this rapid disintegration, accelerated by penetration of the sea through Hudson Strait, only small fluctuations of the northeast margin occurred. In this broad context the northeast margin exists today in the form of the Barnes Ice Cap's fronting onto Conn and Bieler lakes. The full topographic-climatic analysis of this contrast cannot be considered here. However, it is obvious that during late-Wisconsin time the north-central Canadian Arctic witnessed rapid contractions of the ice margin, while the northeast margin, backed by the great accumulation area of the Baffin uplands, was comparatively stable. Such contrasts in the regime of different sections of the same ice sheet should not be considered abnormal. Current studies on the regime and past history of the Barnes Ice Cap indicate that even with a relatively small ice mass, sections of the perimeter may be advancing while other sections are stable or in retreat. The broad picture of differences in degree of marginal fluctuation is represented schematically in Figure 6.

Another aspect of the Cockburn moraine problem is the determination of the centre, or centres, of dispersal that existed when the periphery of this sub-continental ice sheet coincided with the general limit of the moraine system. Related to this is the manner and timing of the penetration of salt water through Hudson Strait. Løken (1962) has established that the Sheppard moraines on the west side of the Torngat Mountains are probably less than 9,000 years old and were related to a large mass of ice lying over Ungava Bay. The very extensive Naskaupi ice-dammed lakes of the northeast Labrador-Ungava upland also required a large mass of ice in Ungava Bay: these lakes came into existence later than 9,000 years ago (Ives, 1960a and b). This implies that Hudson Strait and Bay were still occupied by the continental ice sheet. It seems probable, therefore, that the centres of dispersal during the Cockburn phase were Hudson Bay and Foxe Basin. The northward bulge in the outline of the Cockburn moraines between the west coast of Melville Peninsula and northeast coast of Baffin Island forms a significant perimeter between 150 and 200 km beyond the Foxe Basin coastline.

Mollusc shells collected from Deception Bay on the south side of Hudson Strait west of Ungava Bay have yielded an age of 10,450 ± 250 years (Ives, 1963, I-488). The shells were collected by B. Matthews from a height of 87 metres and their age is difficult to explain in the light of the evidence presented by Løken (1962) and the thesis on deglaciation that is being developed here. Additional shell samples collected by Matthews from the Deception Bay area and dated through the Geographical Branch have yielded ages of approximately 7,500 years. Three samples were collected from between 105 and 110 metres above sea level and have all yielded closely similar results. With the one exception, noted above, it is perhaps significant that all late- and postglacial samples so far collected from within the perimeter of the Cockburn moraines and west of Cape Chidley are less than 8,000 years old.

So far the discussion has been restricted to the northern half of the Cockburn ice sheet. It may be premature to attempt correlations with moraine systems in southern Canada, although the ice sheet obviously had a southern margin: some tentative discussion, therefore, might stimulate more extensive interest in the general problem.

The Lake Athabasca-Cree Lake moraine, as a possible southwestern correlative, has already been mentioned. South of Hudson Bay Prest (1963) has documented the large Agutua moraine in northwestern Ontario. Elson (1957), on the basis of

detailed investigations of the glacial Lake Agassiz levels, has correlated the Lac Seul moraine with the Valders glacial phase. More recently Prest (1963) has obtained a radiocarbon date (8,800 ± 250; GSC-9) from gyttja collected from a kettle hole on this moraine and suggests that gyttja accumulation began shortly after Lake Agassiz fell 66 metres from its highest stand on the moraine. This date is therefore compatible with Elson's conclusion. When Lake Agassiz reached its highest level, partially drowning the Lac Seul moraine, the ice margin had retreated to an undetermined position farther northeast. The Agutua moraine lies 200 km to the northeast: from the work of Elson and Prest it can be inferred that this moraine is younger than the radiocarbon-dated gyttja because the retreating ice margin rapidly opened lower outlets to the Lake Superior basin, thus lowering the level of Lake Agassiz and exposing the kettle hole. This, combined with the general alignment of the Agutua moraine with the southern edge of the Cochrane till and the Lake Athabasca-Cree Lake system, prompts the tentative correlation of all three. Farther east Terasmae and Hughes (1960) showed that the deglaciation in the Cochrane area occurred more than 7,875 ± 200 years ago (GSC-14); this date was obtained from mollusc shells collected below the marine limit south of James Bay. The approximate dating of the Cockburn system in northern Canada is based on the age of shells obtained in localities where the ice sheet was apparently nearly contiguous with the sea, the shells having been deposited on the distal side of the moraine system. The marine transgression south of James Bay, however, was dependent upon the disintegration of ice centred over Hudson Bay, and the shell localities of Terasmae and Hughes are north of the southern limit of the Cochrane till. Thus the time interval between the formation of the Cochrane till and deposition of the 7,875-year old shells is probably greater than that between construction of the MacAlpine moraine, for instance, and the deposition of Blake's 8,200-year old shells.

CONCLUSION

Much more field work remains to be done, particularly on the morphologic and stratigraphic relations of the various members of the great moraine belt of northeastern Baffin Island and on their association with the marine overlap. The present paper, however, is intended as a preliminary review of implications of the disposition of extensive moraine units in eastern and central Arctic Canada. Although hypothetical to a considerable degree there has been placed on the map a major end-moraine system more than 2,000 km in extent where a virtual blank had existed prior to the instigation of the Geographical Branch Baffin Island program in 1961. It is proposed that a major stillstand, or readvance phase, the Cockburn phase, occurred between 8,000 and 9,000 years ago. It is further proposed that the Cochrane Readvance and the marginal fluctuation responsible for the construction of the moraines stretching almost 300 km between Sandy Lake and the upper Albany River in northwestern Ontario (Agutua moraine) probably occurred during the Cockburn phase. The various members of this system of end moraines, therefore, could be considered as approximately contemporaneous. It is suggested that the Cochrane, Sandy Lake-Albany River, Lake Athabasca-Cree Lake, MacAlpine, Melville Peninsula and the Cockburn of eastern Baffin Island be linked together under the name "Cockburn Moraine System." Thus the term "Cockburn Phase" should be applied on a regional scale to mark an important glacial phase in the late-Wisconsin history of Canada: this is shown schematically as Figure 7. Finally, the concept of rapid, continual recession of the ice-sheet margin from the Keewatin north coast to its ultimate disintegration in the region of the Keewatin ice divide must be modified. Further work in northeast Baffin Island should result in the gradual unravelling of a large span of Pleistocene time and the moraines which were initially fitted into the simplified Clyde and Cockburn phases (Ives and Andrews, 1963) are probably a major key to this chronology.

ACKNOWLEDGMENTS

The early air photograph interpretation of G. Falconer, undertaken in 1955 as preparation for the Glacial Map of Canada, together with the early Geographical Branch work in Baffin Island, provided the germ from which the central thesis of this paper grew. Miss Jane Philpot, research assistant, carried out an important part of the tracing of the Cockburn moraines from air photographs. The writers are indebted to other members of the Physical Geography Division of the Branch for discussion and criticism and also to J. E. Smith for the collection of marine shells during 1964 field work in Sam Ford Fiord.

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POSTSCRIPT

Since going to press a publication by Craig (1965b) has come to our attention. As this paper is devoted entirely to a commentary on our concept of the "Cockburn Phase" and as it contains additional radiocarbon dates, this short recapitulation is appended. Craig summarizes his review of the Cockburn Phase concept as follows (Craig, 1965b, pp. 5-6):

> "Thus, although . . . the distribution of the moraines does not provide an adequate basis for reconstruction of an ice marginal position between C and D (mid-Melville Peninsula and Milne Inlet, Baffin Island)* as shown by Falconer *et al.*, the available radiocarbon dates do not contradict such a reconstruction. The opening of Hudson Bay-Foxe Basin to the sea further complicates the picture as presented by Falconer *et al.* If the entry of the sea overlapped the time of formation of the morainal features discussed above, as suggested by some radiocarbon dates, their concept of a diminished Wisconsin ice-sheet is not appropriate."

It is not clear from this paragraph whether Craig supports our conclusions but wants to indicate that they are merely good guesswork without basic factual support, or whether he entirely disagrees with the Cockburn Phase concept. If the latter, then he faces the difficulty of providing an alternate interpretation of the available evidence; he makes no attempt to do this. The only apparent alternative is that the separate moraine units on the Keewatin mainland, on Melville Peninsula and on Baffin Island, were formed at the margins of separate ice sheets after the sea had entered Foxe Basin-Hudson Strait. We reject this as improbable, (a) because it cannot be a coincidence that end moraines were preserved only on the "outside" margins of the three theoretical ice masses (see our Figure 1), (b) because the three main units form a cohesive whole when viewed on a small scale map. Furthermore, Craig's concern with the difficulty of providing sufficient time between our Cockburn Phase and encroachment of the sea into Foxe Basin-Hudson Bay seems to be the result of thinking along preconceived lines. The advent of radiocarbon dating in the early 1950's and the following 15 years' progress in Quaternary research have witnessed the progressive contraction of the late-Wisconsin time scale. In the present case we are considering the final phases in the break-up of an ice sheet centred over areas presently below sea level that were even more depressed isostatically 7,000 or more years ago; that break-up could well have reached catastrophic proportions. With the eventual disruption of the Cockburn Ice Sheet, remnants undoubtedly persisted on the Keewatin mainland (Craig and Fyles, 1960) and on Melville Peninsula (Sim, 1960a and b; 1963) but these represented final melt phases and moraine-building was very limited or non-existent.

There are some specific points related to Craig's text. Nine new radiocarbon dates are provided which, in the writer's own words "do not contradict" our conclusions; nor do they add significantly to them except insofar as they provide general substantiation. The most significant are numbers 3, 4 and 5 (Craig, 1965b, Figure 2), located on the Hudson Bay-Foxe Basin side of the moraines. They are all within 100 years of the date obtained from shells collected near the marine limit on the southwest coast of Baffin Island (6,750 $\pm$ 250; I-406/G.B.-V.W.S. 61-1S: Ives and Andrews, 1963). On page 3 Craig remarks: "Between these two zones (i.e. between C and D, figure 2) a complex of small morainal segments occurs along the northern third of the west side of Melville Peninsula (Craig, 1965)." Sim (1960a, 1963) originally mapped these features; his work and our own more detailed air photograph interpretation show that Craig's Figure 2 has many omissions and that the gap between his C and D is less significant than his Figure 2 implies (see our Figures 1 and 5). Finally, the maps in Craig's original publications (1961, 1964) on the glacial features of northern Keewatin show only small lengths of the end moraines, and he states (Craig, 1961, p. 2):

> "This area is part of the central zone of the Wisconsin ice-sheet, within which the ice-margin retreated rapidly and regularly with *no periods of marginal fluctuation* (Craig and Fyles, 1960, pp. 6-7). A short period of still-stand is represented by the end moraines, but *these are neither extensive nor of great size and probably can be related to local topographic conditions.*"*

* Our note in brackets.

* Our italics.

At least we have provided proof that extensive sections of moraine exist on a hitherto unsuspected scale. Our current paper is only "intended as a preliminary review of implications of the disposition of extensive moraine units in eastern and central Arctic Canada"; we do not expect it to be the last word; indeed, the work has barely begun.

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GEOGRAPHICAL BULLETIN, VOL. 7, NO. 2, PP. 155-156, 1965

NATIONAL ADVISORY COMMITTEE ON GEOGRAPHICAL RESEARCH

Dr. F. Kenneth Hare was the first Canadian geographer to draw attention formally to the need for a national approach to geographical research. In his presidential address of May 26, 1964, to the Canadian Association of Geographers, Dr. Hare emphasized the dangers of the pursuit of divergent specializations in geography. He criticized the self-defensive plea of research for its own sake in a country of such youth and vastness that has so much to offer to a well organized geographical profession: "I think that some (but of course not all) of the research done in Canada ought to be aimed directly at helping national development." He went on to urge the establishment of a group that would embrace as its objective a comprehensive national approach to the development of our discipline.

On the 26th and 27th of November, 1964, a special conference of government and university scientists and administrators met in Ottawa to discuss the current status and possible future role of the Geographical Branch and to advise the Minister of Mines and Technical Surveys on its findings. While much of the discussion was of a preliminary and confidential nature, one of the more significant conclusions was the recommendation that the Minister consider the creation of a National Advisory Committee on Geographical Research (Comité consultatif national de la recherche géographique): proposed terms of reference and composition of the committee were discussed.

The Minister acted upon the recommendation of the conference and the National Advisory Committee was established by Order in Council on April 14, 1965. The text of the Order in Council is reproduced below:

P.C. 1965—693

Privy Council Canada
AT THE GOVERNMENT HOUSE AT OTTAWA
WEDNESDAY, the 14th day of APRIL, 1965.

PRESENT

HIS EXCELLENCY
THE GOVERNOR GENERAL IN COUNCIL.

His Excellency the Governor General in Council, on the recommendation of the Minister of Mines and Technical Surveys, is pleased hereby to establish a body to be known as "The National Advisory Committee on Geographical Research", "Le Comité consultatif national de la recherche géographique", with membership, powers, duties and functions as set out below:

1. The National Advisory Committee on Geographical Research (Le Comité consultatif national de la recherche géographique) (hereinafter referred to as the "Committee") shall:
   (a) assist in the co-ordination of geographical research in Canada;
   (b) promote the development of geographical research through the recommendation of grants-in-aid.
2. The membership of the Committee shall consist of:
   the Director, Geographical Branch, Department of Mines and Technical Surveys; up to ten members from Canadian universities; up to four members from federal and provincial government departments, agencies and research councils;
   up to four members from Canadian industrial and business establishments and associations.
3. The membership shall consist of not less than eleven and not more than nineteen members.
4. The Minister of Mines and Technical Surveys, on the recommendation of the Director, Geographical Branch, Department of Mines and Technical Surveys, shall invite individuals to be members of the Committee; the term of such membership shall not exceed three years, which term may be renewed by the said Minister.
5. Unless otherwise designated by the Minister of Mines and Technical Surveys, on the recommendation of the Deputy Minister of Mines and Technical Surveys, the Director, Geographical Branch, shall be Chairman of the Committee.
6. A Secretary may be appointed by the Director, Geographical Branch, from amongst his staff, but the said Secretary shall not be a member of the Committee.
7. The Committee shall meet at least once in every calendar year and the Chairman shall report to the Minister of Mines and Technical Surveys.
8. The Committee may establish sub-committees.
9. Each of the said sub-committees shall be presided over by a Chairman to be appointed by the Committee, such Chairman to be selected from the members of the Committee.
10. The sub-committee Chairman shall be responsible for inviting individuals to serve on his sub-committee.
11. The Chairman of the sub-committee shall report to the Chairman of the Committee as required.
12. All members of the Committee and sub-committees shall serve without remuneration, but, they, as well as the Secretary of the Committee may be paid their travelling and living expenses in attending meetings away from their places of residence.
13. On the authority of the Committee Chairman, the services of specialists may be retained without remuneration for the Committee and sub-committees. They may be paid reasonable travelling and living expenses under the same conditions as for Committee and sub-committee members.

Certified to be a true copy
"R. G. ROBERTSON"
Clerk of the Privy Council

It has been decided that initially the size of the committee will be relatively small and that subcommittees will only be established as the need arises and as the initial membership achieves a working cohesion. It is hoped that the committee will provide an important link between university, government and private geographers, that it will establish close liaison with the Canadian Association of Geographers and other professional bodies and that it will permit the further development of profitable contacts between geographers and members of the cognate disciplines. It is also hoped that research funds will be made available to the committee so that direct stimulation of research can be provided through a system of grants-in-aid.

The initial committee membership is as follows:

Dr. L. Beauregard, Chairman, Institut de Géographie, Université de Montréal

Dr. J. W. Birch, Chairman, Geography Department, University of Toronto

Dr. E. Christiansen, Saskatchewan Research Council

Dr. J. G. Fyles, Pleistocene Section, Geological Survey of Canada

Dr. F. Grenier, Chairman, Institut de Géographie, Université Laval

Dr. J. D. Ives, Director, Geographical Branch

Dr. G. Jacobsen, Tower Construction Company, Montreal

Dr. T. Lloyd, Chairman, Geography Department, McGill University

Dr. J. R. Mackay, Geography Department, University of British Columbia

Mr. P. Marchant, British Newfoundland Corporation

Mr. M. K. Thomas, Climatological Section, Meteorological Branch, Department of Transport

Dr. K. W. Walter, Geographic Advisor, Imperial Oil Limited

Dr. W. C. Wonders, Chairman, Geography Department, University of Alberta (Edmonton)

(J. D. Ives)

GEOGRAPHICAL BULLETIN, VOL. 7, NO. 2, PP. 157-158, 1965

COMITÉ CONSULTATIF NATIONAL DE LA RECHERCHE GÉOGRAPHIQUE

Le Dr F. Kenneth Hare a été le premier géographe canadien à attirer officiellement l'attention sur la nécessité d'une planification à l'échelle nationale de la recherche en géographie. Dans son discours présidentiel du 26 mai 1964 à l'Association canadienne des géographes, le Dr Hare souligna les dangers qu'entraîne la poursuite de spécialisations divergentes en géographie. Il critiqua les tenants de la recherche poursuivie dans son seul intérêt, dans un pays jeune et vaste qui a tant à offrir à un corps professionnel bien organisé de géographes. «Je pense qu'une grande partie de la recherche, mais non la totalité, bien entendu, devrait viser directement au développement national.» Il continua en préconisant la mise sur pied d'un groupe qui choisirait comme objectif le développement des disciplines géographiques sur une envergure largement nationale.

Les 26 et 27 novembre 1964, des hommes de science et des administrateurs tant gouvernementaux qu'universitaires se réunirent en conférence à Ottawa pour discuter de la situation et du rôle futur de la Direction de la géographie, et pour faire part au ministre des Mines et des Relevés techniques de ses conclusions. Bien qu'une grande partie des discussions fût de nature préliminaire et confidentielle, un des résultats les plus significatifs a consisté en une recommandation au ministre d'étudier l'opportunité de créer un Comité consultatif national de la recherche géographique (National Advisory Committee on Geographical Research); le mandat et la composition du Comité ont été discutés.

Le ministre a favorablement accueilli les recommandations des participants à la conférence et un Comité consultatif national fut établi par décret du Conseil en date du 14 avril 1965. Le texte du décret est reproduit ci-dessous:

P.C. 1965-693

«HÔTEL DU GOUVERNEMENT À OTTAWA,
LE MERCREDI 14 AVRIL 1965.

PRÉSENT

SON EXCELLENCE
LE GOUVERNEUR GÉNÉRAL EN CONSEIL.

Il plaît à Son Excellence le Gouverneur général en Conseil, sur la recommandation du ministre des Mines et des Relevés techniques, d'établir un conseil dont le nom sera «Le Comité consultatif national de la recherche géographique» (The National Advisory Committee on Geographical Research), dont l'ensemble des membres, les pouvoirs, les tâches et les fonctions seront les suivants:

1. Le Comité consultatif national de la recherche géographique (The National Advisory Committee on Geographical Research), désigné ci-après comme «le Comité», devra
   a) aider à la coordination de la recherche géographique au Canada,
   b) encourager l'avancement de la recherche géographique en recommandant certaines subventions.
2. L'ensemble des membres du Comité comprendra:
   le directeur de la Direction de la géographie, ministère des Mines et des Relevés techniques; dix membres au maximum, qui viendront des universités canadiennes;
   quatre membres au maximum, qui viendront des ministères, agences et conseils de recherches fédéraux et provinciaux;
   quatre membres au maximum, qui viendront des établissements et corps industriels et commerciaux du Canada.
3. Le nombre des membres ne devra pas être inférieur à onze ni dépasser dix-neuf.
4. Le ministre des Mines et des Relevés techniques invitera des personnalités à faire partie du Comité, sur la recommandation du directeur de la Direction de la géographie. La durée de l'appartenance au Comité ne devra pas dépasser trois ans, sauf en cas de renouvellement par le ministre.
5. Le directeur de la Direction de la géographie sera président du Comité, à moins qu'il n'en soit décidé autrement par le ministre des Mines et des Relevés techniques, sur la recommandation du sous-ministre des Mines et des Relevés techniques.
6. Le directeur de la Direction de la géographie désignera un secrétaire, qu'il choisira parmi son personnel. Ce secrétaire ne sera cependant pas membre du Comité.
7. Le Comité se réunira au moins une fois par année civile et son président fera rapport au ministre des Mines et des Relevés techniques.
8. Le Comité pourra instituer des sous-comités.
9. Chacun des sous-comités aura un président nommé par le Comité et choisi parmi les membres de ce dernier.
10. Le président du sous-comité sera chargé d'inviter des particuliers à siéger audit sous-comité.
11. Le président du sous-comité fera rapport au président du Comité lorsque demande en sera faite.
12. Tous les membres du Comité et des sous-comités rempliront leur charge sans rémunération, mais les dépenses de voyage et de pension encourues par les membres ou le secrétaire pour assister aux réunions loin de leur domicile leur seront remboursées.
13. Sur autorisation du président du Comité, les services de spécialistes pourront être retenus, sans rémunération, pour le Comité et les sous-comités. Ces spécialistes pourront recevoir le remboursement de leurs frais normaux de voyage et de pension, dans les mêmes conditions que les membres du Comité et des sous-comités.

Copie conforme
(signé) R. G. Robertson,
greffier du Conseil privé.»

On a décidé qu'au début, le Comité serait relativement restreint et que les sous-comités seraient créés au fur et à mesure des besoins et de la rapidité avec laquelle le groupe initial de membres acquerra la cohésion nécessaire à son travail. On souhaite que le Comité constitue un lien important entre les universités, le gouvernement et les géographes du secteur privé, qu'il assure des relations étroites avec l'Association canadienne des géographes, et autres organismes professionnels et qu'il permette un développement accru des contacts profitables entre géographes et membres des professions apparentées. On espère également que le Comité disposera de fonds pour la recherche de telle façon qu'il puisse la stimuler directement par un système de subventions.

Le Comité se composera comme suit:

MM. L. Beauregard, président, Institut de géographie, Université de Montréal;
J. W. Birch, président, Département de géographie, Université de Toronto;
E. Christiansen, Conseil de recherches de Saskatchewan;
J. G. Fyles, Section du pléistocène, Commission géologique du Canada;
F. Grenier, président, Institut de géographie, Université Laval;
J. D. Ives, directeur, Direction de la géographie;
G. Jacobsen, Tower Construction Company, Montréal;
T. Lloyd, président, Département de géographie, Université McGill;
J. R. Mackay, Département de géographie, Université de Colombie-Britannique;
P. Marchant, British Newfoundland Corporation;
M. K. Thomas, Section de la climatologie, Direction de la météorologie, ministère des Transports;
K. W. Walter, conseiller en géographie, Imperial Oil Limited;
W. C. Wonders, président, Département de géographie, Université d'Alberta, Edmonton.

(J. D. Ives

BOOK REVIEW

SURFICIAL GEOLOGY, NICHICUN-KANIAPISKAU MAP-AREA, QUEBEC. O. L. Hughes, Geol. Surv. Can., Bull. 106, 1964. 20 p., plus 3 folded maps. Price $1.10.

This Bulletin provides a qualitative description of certain aspects of the surficial geology of a large tract of central Labrador-Ungava. Brief introductory sections cover the general physical geography of the area, the main section deals with terminology and descriptions of the glacial features and concluding sections provide an interpretation of the late-glacial history and generalized economic considerations.

The treatment of the ice-directional evidence well illustrates the complicated nature of the history of ice movements in the area. Consideration of available information on adjacent areas would indicate still greater complexity. A late-phase easterly trend in the southeast of the map area and beyond into the McPhadyen River area is briefly mentioned. This trend, and particularly its northern discontinuity against a strong north-northeast trend, is one of the well known and more spectacular features of the glaciation of central Labrador-Ungava. Wilson used this, in association with Hughes' "Opiscoteo-Guyot" discontinuity, as indicative of an ice divide, although the inference is probably oversimplified (Glacial Map of Canada, Wilson et al., 1958).

Distribution of glacial drainage channels is shown on an accompanying map (Figure 1). Despite the paucity of forms (including all forms, subglacial chutes, overflows between lakes, sections of present stream beds and erosional segments of eskers, a mean density of one channel for each 66 square miles has been plotted) and the lack of actual directional evidence for a large number of them, Hughes has been able to infer the localities of some of the final stagnant remnants of the inland ice. This implied criticism may be invalid if the glacial drainage symbol on the map represents many, rather than a single form; the map legend, however, does not clarify this point.

The author introduces the term "ribbed moraine" to describe a well known and widespread till surface pattern which has long been assumed the product of subglacial activity. The possibility that linear sections of this patterned till were end moraines (Henderson, 1959) has never been seriously considered. The advisability of introducing an additional, and in this instance, cacophonous term, is doubtful, and the use of the terms "ground moraine", "lodgment till" and "hummocky moraine" compound the confusion. Hare (1959) and Ives (1956) used the term rippled till (ripple till) in a purely descriptive manner to imply that the surface of the till deposit in certain areas took on a "rippled" appearance. It is presumably ground moraine (English usage) or till (American usage) with a distinctive surface pattern rather than a series of specific features such as might be implied by "ribbed moraines" (i.e., they are not "moraines" *sensu stricto*).

The maps constitute the main part of the publication and are a valuable contribution to the knowledge of the distribution of glacial landforms and deposits. It is unfortunate, however, that the myriad lakes remain uncoloured and key references to lakes in the text are not provided with coordinates to facilitate "discovery" on the maps. "Lac Guyot" in the text presumably refers to "Lac Gayot" on the map (Figure 1). Hare's contribution to physical geography is acknowledged as "surficial geology" in the map legend (Figure 2), and it is to be regretted that the preface and body of the text imply that the large amount of geographical work done in Labrador-Ungava is either unknown to the writer, or else is passed off as "surficial geology".

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Henderson, E. P.
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Ives, J. D.
1956 : Till patterns in central Labrador. *Can. Geogr.*, no. 8, 25-33.

Wilson, J. T., *et al.*
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(J. D. Ives)

ERRATA

The author of the paper "The Geography of the Orchard Industry of Canada", appearing in vol. 7, no. 2, pp. 27-71, *Geographical Bulletin*, has indicated that several omissions have reduced the usefulness of his paper.

Figure 2, as originally submitted, contained circle graphs showing the total acreage of orchard and the percentage distribution of different tree-fruit crops by province. The omission of this figure explains the reference in the text to a map of the Annapolis Valley on the page where the whole orchard industry of Canada is being discussed (p. 29). The map of the Annapolis Valley (Figure 2 in the published paper) should have been placed in the section where the author discusses the orchard industry of Nova Scotia (pp. 34-39).

Circle graphs have also been deleted from Figures 6 and 7. These graphs gave acreages and percentage distribution of tree-fruit crops for the major orchard regions of Ontario and British Columbia. The method of presentation was the same as that used by Olmstead (*Econ. Geog.* 1956) in order to facilitate comparison with his maps of American orchard regions.

Corrected figures will be published in a future issue of *Geographical Bulletin.*

There are also several errors in Table 7, p. 48. The 1961 acreage of cherries for Ontario should read *5,900* instead of 5,000. In the same table, the third and fourth columns should read *pounds* instead of bushels for cherries, pears, and plums and prunes.

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